

NUTRITION OF HEVEA BRASILIENSIS

III. THE INTERRELATIONSHIPS OF MAGNESIUM, POTASSIUM AND PHOSPHORUS

By

E.W. BOLLE-JONES

Seedlings of Hevea brasiliensis, clone Tjirandji 1, were grown in pot sand culture at varying levels of magnesium, potassium and phosphate supply. A close interrelationship between these three nutrients was demonstrated which affected the growth and composition of the plant. Concentrations of rubber in stems and petioles varied slightly with nutrient levels, and were inversely related to the dry weight values. Points of practical importance arising from the results are discussed.

It has been assumed that the interveinal yellowing frequently observed in leaves of *Hevea brasiliensis* was due to magnesium deficiency, as discussed in the annual reports of the Soils Division for 1949, 1950 and 1952. This view has been confirmed not only by pot culture investigations which have established the appearance of magnesium deficiency symptoms (BOLLE-JONES 1954b) but also by the recent results of field experiments in which the addition of magnesian limestone to affected areas cured the deficiency. This interveinal yellowing, due to magnesium deficiency, is of widespread occurrence in Malaya.

The largest positive growth response of *Hevea brasiliensis* trees to fertilisers in the field is usually obtained on the application of phosphate (HAINES and CROWTHER 1940; AKHURST and OWEN 1950; CONSTABLE and HODNETT 1953), which is, in consequence, regularly applied. This fact, taken in conjunction with the widespread occurrence of magnesium deficiency, suggested that a study of the effects of varying levels of magnesium and phosphate supplies on the growth and composition of *Hevea brasiliensis* in sand culture was necessary.

Neither DE HAAN (1950) nor RHINES, MCGAVACK and LINKE (1952) found any relation between the phosphorus status of *Hevea brasiliensis* and the magnesium content of the leaves but BOLLE-JONES (1954b) reported that laminae of phosphorus deficient plants possessed a low magnesium content. For crops other than *Hevea brasiliensis* some of the published evidence suggested that uptake of phosphorus was positively correlated with magnesium supply or content (BEESON, LYON and BARRENTINE 1944; TRÜOG, GOATES, GERLOFF and BERGER 1947; TUCKER and SMITH 1952) while other reports (CHAPMAN 1953; EAVES and KELSALL 1954) indicated that high phosphorus supplies caused magnesium deficiency to appear.

Magnesium deficient laminae of *Hevea brasiliensis* contained more potassium than healthy laminae (DE HAAN 1950; RHINES *et alii* 1952; BOLLE-JONES 1954b) and a negative correlation existed between both minerals in the leaf (BEAUFILS 1954); laminae of plants of low potassium status contained more magnesium (DE HAAN 1950; RHINES *et alii* 1952; BOLLE-JONES 1954b) and more phosphorus (CHAPMAN 1941; RHINES *et alii* 1952; BEAUFILS 1954; BOLLE-JONES 1954b) than healthy laminae. For other crops the inverse relationship between magnesium and potassium was evident in reports by BOYNTON and BURRELL (1944), WALSH and O'DONOHUE (1945), KIDSON (1947), CAIN (1948, 1953), MERRILL, POTTER and BROWN (1953) and MULDER (1952) and the positive effect of potassium deficiency on phosphorus accumulation was observed by WALL (1940), WALLACE and BEAR (1949) and EVANS, LATHWELL and MEDERSKI (1950).

Hence it was obvious that any study of the interrelationship of magnesium and phosphorus in *Hevea brasiliensis* must take into consideration the potassium status of the plant. Accordingly a factorial experiment was designed in which Tjirandji 1 seedlings were grown in sand culture at three different levels of each of magnesium, potassium and phosphate; the growth and composition of these seedlings were examined at intervals.

A preliminary report of this investigation has been given elsewhere (BOLLE-JONES 1954c).

EXPERIMENTAL

There were 27 treatments, each of which was derived from a different combination of the following magnesium (Mg), potassium (K) and phosphate (P) levels.

Mg₁, K₁, P₁ 0.5 milligram equivalents/litre

Mg₂, K₂, P₂, 2.0 milligram equivalents/litre

Mg₃, K₃, P₃ 8.0 milligram equivalents/litre

Each treatment or 'plot' consisted of three pots and was carried out in duplicate. Twelve 'selfed' Tjirandji 1 seeds were sown in each pot on 10 February 1953. Later (9 March) when the seeds had germinated the seed residue was carefully excised and removed from each seedling so that the plant became completely dependent on minerals supplied to it in the nutrient solution. Complete plants were removed from each pot and the total dry weight of shoots and roots recorded on the following dates: 21 April; 12 May; 24 June; 28 July; 2 October (final sampling).

Fully expanded laminae from which the midribs were excised and discarded were taken from different whorl positions and analysed for chlorophyll and mineral concentrations; the uppermost leaf whorl is always designated as the top whorl while the successive lower one is referred to as the second. The stems and petioles of plants sampled from a plot, with the exception of the July sampling, were bulked together prior to drying, milling and

rubber extraction; for the July sampling the procedure was similar but the green part only of the stems was bulked with the petioles prior to milling and extraction.

The pots, the cold acid leaching of the sand and the analytical procedures employed have been described (BOLLE-JONES 1954a). Tapwater was used for the preparation of the nutrient solutions. Calcium, nitrate and iron were applied at 4.0, 7.0 and 1.0 milligram equivalents per litre respectively to each treatment. Unavoidable variation in Na^+ and SO_4^{--} concentrations occurred. The Na^+ concentration ranged between 1 and 8 meq/l and generally decreased with either Mg or K but increased with P level. The SO_4^{--} concentration ranged between 3 to 12.5 meq/l and increased with either Mg or K level; phosphate level did not markedly affect it. The micronutrients were supplied in concentrations already reported (BOLLE-JONES 1954a).

The numerical data are presented in the form of two way tables which facilitate the ready inspection of the overall trends and the interpretation of interaction effects; included in each table is the respective standard error.

RESULTS

VISUAL OBSERVATIONS

The tallest plants at the end of the experiment grew in the $\text{Mg}_1\text{K}_2\text{P}_2$ treatment (113 cm) and the smallest in the $\text{Mg}_3\text{K}_2\text{P}_2$ (82 cm). Increased magnesium level, initially, produced an increase in height but later it generally depressed elongation except in the K_3 plants in which an increase was still obtained. Increased potassium level generally decreased the height, especially in the Mg_1 plants; this effect was not always linear as some increase was obtained at the K_2 level. Phosphate addition markedly decreased the height in the Mg_1K_3 treatments.

Increased magnesium supply produced an overall increase in the number of leaflets per plant; this effect was most marked in the higher K and P treatments. Potassium addition decreased the number of leaflets, especially those of the Mg_1 plants. Phosphate addition produced an overall increase in the number of leaflets; this effect was well marked at the lower K levels. Neither the number of leaflets nor the height measurements are presented here.

Magnesium deficiency symptoms (BOLLE-JONES 1954b) first appeared (April) at the P_3 level in the midstem leaves of the Mg_1K_2 and Mg_1K_3 plants (*Figure 1*); later (May) it became apparent at all phosphate levels of these treatments but remained more severe at the higher P levels (*Figure 2*). Less severe symptoms were observed in the Mg_2K_3 plants at a later date. Magnesium deficiency was not observed in the Mg_3 plants; thus the symptoms were mainly confined to the lower Mg levels of the higher K and P treatments (*Figures 1 and 2*).



Figure 1. The effect of increased potassium level on the incidence of magnesium deficiency in the Mg_1P_3 treatments, August: $Mg_1K_1P_3$, low potassium (left) and $Mg_1K_3P_3$, high potassium (right). Note: (i) chlorotic mottling and tip scorch in midstem laminae of K_1 plant ascribed to potassium deficiency and possibly slight iron deficiency effects, and (ii) marked interveinal yellowing near midribs of lower laminae of K_3 plant due to the initiation of magnesium deficiency.

Symptoms tentatively ascribed to potassium deficiency first appeared (early May) in the high magnesium-low potassium plants as a yellowish mottling of the lower whorl laminae followed by a tip and marginal scorch; these symptoms were soon obvious at all Mg levels (Figure 3). The scorching effects were largely confined to the low potassium-high phosphate treatments at all magnesium levels (October). The mottling was probably contributed to in some degree by iron deficiency effects but where these latter effects were obvious (as in the K_1P_3 treatments) they usually appeared in the top whorl as a marked chlorosis.

Phosphorus deficiency was manifested (late May) as a purplish tinting of the underside of the younger or second whorl laminae accompanied by restricted growth and few leaves; these effects were usually less severe at the higher Mg levels (Figure 3). This was later (September-October) followed, in severe instances, by a necrosis of the leaf tip which turned upwards and frequently became twisted, while the margins inrolled towards the upper surface (Figure 4). The tinting effect did not necessarily precede the other symptoms on the same lamina but both generally occurred on the same plant. Both types of symptom were first observed in the P_1 treatments with a tendency to appear first at the Mg_1 level. The tip necrosis and upward curling, although associated with a low phosphate supply and related to phos-



Figure 2. The effect of increased phosphate level on the incidence of magnesium deficiency in the $Mg_1 K_2$ treatments, August: $Mg_1 K_2 P_1$, low phosphate (left) and $Mg_1 K_2 P_2$, normal phosphorus (right). Note: (i) mild phosphate deficiency of P_1 plant, and (ii) severe magnesium deficiency in lower leaves of P_2 plant.

phorus deficiency tinting effects, may however be directly due to an induced deficiency of calcium, but as deficiency symptoms of the latter have not been established the uncertainty remains.

An interesting example of the effect of nutrient level variation on the metabolism of *Hevea brasiliensis* was the effect of K level on the $Mg_1 P_1$ plants. Thus when potassium was applied at the K_2 level marked phosphorus deficiency and slight magnesium deficiency effects occurred but at the K_3 level magnesium deficiency was predominant.

TOTAL DRY WEIGHT PER PLANT (SHOOT + ROOT)

TABLE I—The addition of magnesium produced an overall increase in the dry weight of the plants for the earlier months (up until July); this increase was highly significant for both May and June samplings and was especially marked at the P_3 level in June (significant MgP interaction). Later, this increase was apparent in the K_3 treatments only.

Increased supplies of potassium produced an overall decrease in the dry weight; at first this decrease was linear but later the K_2 plants produced a greater dry weight than either the K_1 or K_3 plants. The detrimental effect of potassium addition on dry



Figure 3. The effect of magnesium level on the vigour of the $K_1 P_1$ plants, September: $Mg_1 K_1 P_1$, low magnesium (left) and $Mg_2 K_1 P_1$, normal magnesium (right). Note: (i) 'thin' small leaved appearance of Mg_1 plant mainly due to phosphorus deficiency, and (ii) more vigorous appearance of Mg_2 plant and the occurrence of symptoms ascribed to potassium deficiency.



Figure 4. $Mg_3 K_3 P_1$ plant, late September. Note marginal and tip scorch with inward rolling of the margin and upward turning of lamina tip. Symptoms associated with a severely reduced phosphate status, but possibly partially due to calcium deficiency effects.

TABLE 1: TOTAL DRY WEIGHT OF PLANT (SHOOT + ROOT)
Grams

Level	April			May			June			July			October			
	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean
Mg ₁	(±0.16)	(±0.09)		(±0.16)	(±0.28)			(±0.33)	(±0.58)			(±2.1)	(±8.0)			(±4.6)
Mg ₂	3.1 3.0 2.8	3.0		4.7	5.3 4.8 4.0		9	12	14 14 9		23 21 9	18	59 69 23			50
Mg ₃	3.4 3.2 2.9	3.2		5.6	5.7 5.8 5.4		14	15	15 16 14		22 22 18	21	52 61 44			52
	3.4 3.2 3.0	3.2		5.6	5.7 5.8 5.4		14	15	15 17 14		19 22 22	21	47 56 35			46
Level	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean
K ₁	(±0.16)	(±0.09)		(±0.16)	(±0.28)			(±0.33)	(±0.58)			(±2.1)	(±8.0)			(±4.6)
K ₂	3.4 3.4 3.1	3.3		5.6	5.8 6.2 4.7		14	14	14 16 14		18 25 23	22	47 56 54			52
K ₃	3.2 3.3 2.8	3.1		5.4	5.5 5.9 4.9		14	16	17 15		21 22 22	22	54 67 65			62
	2.9 2.9 2.9	2.9		4.9	5.0 5.5 4.3		13	12	13 13 12		15 16 17	16	33 41 27			34
Level	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean
P ₁	(±0.16)	(±0.09)		(±0.16)	(±0.28)			(±0.33)	(±0.58)			(±2.1)	(±8.0)			(±4.6)
P ₂	3.0 3.1 3.4	3.2		5.4	5.0 5.6 5.6		13	14	14 14 14		18 16 20	18	39 50 46			45
P ₃	3.1 3.1 3.4	3.2		5.9	5.4 5.7 6.5		13	16	16 16 16		18 23 22	21	68 50 45			55
	2.9 3.3 2.7	3.0		4.6	3.8 5.4 4.7		10	15	16 16 16		17 23 22	21	44 56 46			49
Sig. effects	P < 0.05	P < 0.01		P < 0.01	P < 0.05			P < 0.01	P < 0.05			P < 0.01	P < 0.05			P < 0.01
Linear		K		Mg, P	K			Mg, K	Mg			K				K
Quadratic	—	—		P	Mg			Mg, K, P	—			—				K
Overall	K, Mg × P	—		Mg, P	K			Mg, K, P, Mg × K	Mg × P			K, Mg × K				K

weight was usually far more severe in the Mg_1 treatments than in the Mg_3 (significant MgK interaction).

Phosphate addition generally produced an overall decrease in dry weight for the earlier months; this effect usually varied with Mg level (significant MgP interaction). Later, the P_2 and P_3 plants gained considerably in weight and increases with phosphate level were obtained.

RUBBER CONCENTRATION IN STEMS AND PETIOLES

TABLE II—The effect of increased nutrient level on rubber concentration was not always consistent from month to month.

The addition of magnesium decreased the concentration of rubber for the earlier months (April, May); this decrease was significant at the May sampling. No consistent effect of magnesium level was apparent in June and July but a slight overall increase was obtained in October.

The addition of potassium produced an overall increase in rubber concentration in the April, May and June samplings; this effect was significant for April and June. Later (October) potassium addition produced a decreased concentration.

A significant increase in rubber concentration due to phosphate addition was obtained in June and July; the phosphate effect was more marked at the lower Mg levels and this resulted in a significant MgP interaction.

CHLOROPHYLL CONCENTRATION IN THE LAMINAE

TABLE III—Increased levels of magnesium usually produced an overall increase in chlorophyll concentration although opposite trends were noted for the top whorl laminae of the June and July samplings. This positive effect of magnesium was significant for both second and third whorl laminae in May.

In general, with the exception of the October sampling, increased potassium level produced an overall increase in the chlorophyll concentration. Positive significant effects due to potassium were recorded at all samplings.

Increased levels of phosphate caused reductions in chlorophyll concentration at the earlier samplings (April-June); later samplings revealed a diminution of this effect. The depressive influence of phosphate on chlorophyll concentration was highly significant for the second whorl laminae at the June sampling.

MINERAL CONCENTRATIONS IN THE LAMINAE

After removal, the seed residues were analysed. It was found that the seedlings usually removed a higher proportion of potassium and phosphorus (76 per cent and 75 per cent respectively) than of magnesium (52 per cent) from the reserves present in the ungerminated seed. Increased levels of potassium decreased the amounts of magnesium or potassium translocated from the seed whereas increased magnesium levels increased the amount of phosphorus translocated. These variations although

TABLE II: THE CONCENTRATION OF RUBBER IN BULKED STEMS AND PETIOLES WITH EXCEPTION OF JULY SAMPLING WHERE 'GREEN' PART ONLY OF STEMS BULKED WITH PETIOLES

Mg rubber/5 gm dry tissue

Level	April			May			June			July			October			
	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean
Mg ₁	(±2.0)			(±1.1)	(±5.5)			(±3.2)	(±3.6)			(±2.0)	(±7.2)			(±4.2)
Mg ₂	81	75	81	79	91	97	98	95	61	60	69	63	96	95	93	95
Mg ₃	75	74	82	77	80	83	91	85	60	69	67	65	95	95	94	95
	79	75	77	77	81	87	82	83	56	66	66	62	98	96	97	97
Level	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean
K ₁	(±2.0)			(±1.1)	(±5.5)			(±3.2)	(±3.6)			(±2.0)	(±7.2)			(±4.2)
K ₂	79	76	81	78	95	76	82	84	55	58	63	59	88	101	100	96
K ₃	73	73	78	75	92	84	90	89	58	67	70	65	87	101	99	95
	80	78	81	80	89	91	90	90	64	65	73	67	90	94	100	95
Level	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean
P ₁	(±2.0)			(±1.1)	(±5.5)			(±3.2)	(±3.6)			(±2.0)	(±7.2)			(±4.2)
P ₂	80	76	77	77	105	86	85	92	61	56	60	59	85	83	97	88
P ₃	77	74	74	75	82	87	82	84	57	65	69	63	98	105	92	98
	80	80	80	80	99	81	83	88	72	75	59	68	101	96	102	100
Sig. effects	P < 0.05			P < 0.01	P < 0.05			P < 0.01	P < 0.05			P < 0.01	P < 0.05			P < 0.01
Linear	—			—	—			Mg	—			K, P	—			—
Quadratic	P			K	—			—	—			—	—			—
Overall	P			K	Mg			—	K, P			Mg × P	—			—

TABLE III: CONCENTRATION OF CHLOROPHYLL IN LAMINA
Mg chlorophyll/gm dry lamina

Mg chlorophyll/gm dry lamina																	(continued opposite)			
Level	April 2nd Whorl				May 2nd Whorl				May 3rd Whorl				June Top Whorl							
	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean				
Mg ₁	(±0.18)				(±0.10)				(±0.14)				(±0.17)				(±0.34)			
Mg ₂	6.7	7.2	7.4	7.1	6.0	6.4	5.5	6.0	6.4	6.0	5.6	6.0	5.0	5.9	4.9	5.3				
Mg ₃	7.3	7.2	7.4	7.3	6.3	6.5	6.2	6.3	6.5	6.6	7.1	6.7	4.9	4.7	5.1	4.9				
Mg ₃	7.2	7.1	7.5	7.3	6.5	6.8	6.3	6.6	6.4	6.9	6.9	6.7	4.6	5.0	5.0	4.9				
Level	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean				
K ₁	(±0.18)				(±0.10)				(±0.14)				(±0.17)				(±0.34)			
K ₂	7.1	7.3	6.9	7.1	6.3	6.2	6.1	6.2	6.8	6.5	5.9	6.4	5.3	4.8	4.4	4.8				
K ₃	7.2	7.2	7.2	7.2	6.7	6.5	6.5	6.6	6.9	6.4	6.1	6.5	5.4	5.0	5.2	5.2				
K ₃	7.9	7.0	7.4	7.4	5.9	6.2	6.0	6.0	6.5	6.3	6.8	6.5	5.2	5.0	4.9	5.0				
Level	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean				
P ₁	(±0.18)				(±0.10)				(±0.14)				(±0.17)				(±0.34)			
P ₂	7.5	7.4	7.3	7.4	6.0	6.5	6.4	6.3	6.3	6.8	7.1	6.7	5.7	5.1	5.0	5.3				
P ₃	6.8	7.3	7.3	7.1	5.8	6.4	6.7	6.3	6.0	6.7	6.6	6.4	5.3	4.8	4.6	4.9				
P ₃	7.0	7.3	7.2	7.2	6.0	6.0	6.5	6.2	5.7	6.7	6.5	6.3	4.8	4.8	4.9	4.8				
Sig. effects	P < 0.05				P < 0.01				P < 0.05				P < 0.01				P < 0.01			
Linear	K				—				Mg				—				—			
Quadratic	—				—				K				—				—			
Overall	K × P				—				Mg, K				—				—			

(continued from opposite)

June 2nd Whorl				July Top Whorl				October Top Whorl				October 2nd Whorl				Level
K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	
(±0.19)				(±0.24)				(±0.32)				(±0.47)				Mg ₁ Mg ₂ Mg ₃
4.2	5.0	4.5	4.6	5.8	6.0	5.7	5.8	6.1	5.4	6.0	5.8	5.8	5.8	4.8	5.5	
4.4	4.3	4.8	4.5	5.2	5.6	5.7	5.5	6.6	5.5	6.2	6.1	5.8	5.9	6.2	6.0	
4.3	4.9	4.9	4.7	5.2	5.8	5.3	5.4	5.9	6.2	6.4	6.1	6.2	5.8	6.0	6.0	
P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	Level
(±0.19)				(±0.24)				(±0.32)				(±0.47)				K ₁ K ₂ K ₃
5.1	3.9	3.9	4.3	5.6	5.1	5.4	5.4	5.6	7.2	6.0	6.2	6.0	5.9	6.0	6.0	
5.4	4.6	4.2	4.7	5.7	5.8	6.0	5.8	6.0	5.3	5.7	5.7	6.1	5.4	6.0	5.8	
5.2	4.6	4.4	4.7	5.4	5.7	5.5	5.6	7.0	5.8	5.8	6.2	5.0	5.5	6.5	5.7	
Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Level
(±0.19)				(±0.24)				(±0.32)				(±0.47)				P ₁ P ₂ P ₃
5.2	5.4	5.1	5.2	5.6	5.5	5.6	5.6	6.3	6.2	6.2	6.2	5.3	6.1	5.8	5.7	
4.5	4.1	4.6	4.4	5.8	5.5	5.5	5.6	6.2	6.3	5.8	6.1	5.6	5.6	5.6	5.6	
4.1	4.0	4.4	4.2	6.1	5.5	5.2	5.6	5.1	5.9	6.5	5.8	5.6	6.3	6.5	6.1	
P < 0.05				P < 0.05				P < 0.05				P < 0.05				Sig. effects
K				—				—				—				Linear
P				K				K				—				Quadratic
K				—				—				—				Overall

TABLE IV: CONCENTRATION OF MAGNESIUM IN LAMINA

% Mg in dry lamina																	(continued opposite)			
Level	April 3rd Whorl				May 2nd Whorl				May 3rd Whorl				June Top Whorl							
	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean				
Mg ₁ Mg ₂ Mg ₃	(±0.012)				(±0.007)				(±0.012)				(±0.007)				(±0.011)			
	.11	.10	.08	.09	.07	.06	.05	.06	.07	.06	.04	.06	.16	.15	.15	.15				
	.18	.17	.13	.16	.14	.12	.09	.12	.18	.13	.09	.14	.23	.23	.22	.22				
	.40	.35	.27	.34	.29	.24	.21	.25	.47	.37	.26	.37	.35	.34	.29	.33				
Level	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean				
K ₁ K ₂ K ₃	(±0.012)				(±0.007)				(±0.012)				(±0.007)				(±0.011)			
	.22	.25	.22	.23	.16	.17	.18	.17	.23	.25	.24	.24	.24	.24	.26	.25				
	.22	.19	.20	.20	.14	.14	.14	.14	.17	.19	.20	.19	.22	.24	.25	.24				
	.16	.16	.16	.16	.12	.13	.11	.12	.13	.14	.12	.13	.20	.22	.23	.22				
Level	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean				
P ₁ P ₂ P ₃	(±0.012)				(±0.007)				(±0.012)				(±0.007)				(±0.011)			
	.10	.16	.33	.20	.06	.12	.24	.14	.06	.13	.34	.18	.15	.22	.30	.22				
	.09	.16	.35	.20	.06	.12	.27	.15	.05	.14	.40	.20	.15	.22	.33	.23				
	.09	.16	.33	.19	.07	.11	.24	.14	.05	.14	.36	.18	.16	.23	.36	.25				
Overall	P < 0.05				P < 0.01				P < 0.05				P < 0.01				P < 0.05			
Quadratic					Mg, K				Mg, K				Mg, K				Mg, K, P			
Linear					Mg				Mg				Mg				—			
Sig. effects					Mg, K, Mg, × K				Mg, K				Mg, K				K, P			
																	Mg			

(continued from opposite)

June 2nd Whorl					July Top Whorl					October Top Whorl					October 2nd Whorl					Level					
K ₁	K ₂	K ₃	Mean		K ₁	K ₂	K ₃	Mean		K ₁	K ₂	K ₃	Mean		K ₁	K ₂	K ₃	Mean		Level					
(±0.017)					(±0.015)					(±0.009)					(±0.019)					(±0.011)					Mg ₁
.07	.03	.02	.04		.13	.15	.13	.14		.14	.12	.12	.13		.08	.06	.02	.05							
.18	.15	.09	.14		.22	.23	.24	.23		.26	.24	.18	.22		.27	.21	.12	.20		Mg ₂					
.52	.41	.26	.40		.40	.33	.30	.34		.38	.42	.33	.38		.49	.45	.33	.42		Mg ₃					
P ₁	P ₂	P ₃	Mean		P ₁	P ₂	P ₃	Mean		P ₁	P ₂	P ₃	Mean		P ₁	P ₂	P ₃	Mean		Level					
(±0.017)					(±0.015)					(±0.009)					(±0.019)					(±0.011)					K ₁
.20	.28	.29	.26		.24	.25	.27	.25		.25	.26	.26	.26		.25	.30	.29	.28							
.18	.21	.21	.20		.21	.26	.24	.24		.23	.28	.26	.26		.20	.26	.25	.24		K ₂					
.12	.11	.14	.12		.22	.23	.22	.22		.20	.22	.20	.21		.14	.17	.16	.15		K ₃					
Mg ₁	Mg ₂	Mg ₃	Mean		Mg ₁	Mg ₂	Mg ₃	Mean		Mg ₁	Mg ₂	Mg ₃	Mean		Mg ₁	Mg ₂	Mg ₃	Mean		Level					
(±0.017)					(±0.015)					(±0.009)					(±0.019)					(±0.011)					P ₁
.04	.12	.33	.17		.13	.24	.30	.22		.13	.21	.34	.23		.05	.18	.36	.20							
.04	.12	.44	.20		.15	.21	.38	.25		.13	.25	.40	.26		.05	.20	.46	.24		P ₂					
.04	.17	.43	.21		.14	.24	.35	.24		.12	.22	.39	.24		.04	.21	.45	.23		P ₃					
P < 0.05	P < 0.01				P < 0.05	P < 0.01				P < 0.01					P < 0.05	P < 0.01				Sig. effects					
Mg, K, P					Mg					Mg, K					Mg, K, P					Linear					
Mg					—					—					K, P					Quadratic					
Mg, K, P, Mg × K, Mg × P					Mg × P					Mg, Mg × K					Mg, K, P, Mg × K, Mg × P					Overall					

TABLE V: CONCENTRATION OF POTASSIUM IN LAMINA
% K in dry lamina

(continued opposite)

Level	April 2nd Whorl					May 2nd Whorl					May 3rd Whorl					June Top Whorl				
	K ₁	K ₂	K ₃	Mean		K ₁	K ₂	K ₃	Mean		K ₁	K ₂	K ₃	Mean		K ₁	K ₂	K ₃	Mean	
Mg ₁ Mg ₂ Mg ₃	(±0.04)					(±0.05)					(±0.03)					(±0.08)				
	1.1	1.3	1.7	1.4		1.2	1.5	2.4	1.7		0.9	1.2	2.0	1.4		1.1	1.7	2.6	1.8	
	0.9	1.1	1.4	1.2		0.9	1.3	1.8	1.3		0.7	1.0	1.4	1.0		0.9	1.4	2.1	1.5	
Level	0.8	0.9	1.2	0.9		0.8	1.0	1.3	1.0		0.6	0.8	1.1	0.8		0.9	1.1	1.8	1.2	
	P ₁	P ₂	P ₃	Mean		P ₁	P ₂	P ₃	Mean		P ₁	P ₂	P ₃	Mean		P ₁	P ₂	P ₃	Mean	
	(±0.04)					(±0.05)					(±0.03)					(±0.08)				
K ₁	1.0	0.9	0.9	0.9		0.9	1.0	0.9	1.0		0.7	0.8	0.7	0.7		1.0	0.9	1.0	1.0	
K ₂	1.1	1.1	1.2	1.1		1.2	1.2	1.4	1.3		0.9	0.9	1.1	1.0		1.3	1.4	1.5	1.4	
K ₃	1.4	1.4	1.4	1.4		1.8	1.8	2.0	1.8		1.4	1.4	1.7	1.5		1.8	2.4	2.2	2.2	
Level	Mg ₁	Mg ₂	Mg ₃	Mean		Mg ₁	Mg ₂	Mg ₃	Mean		Mg ₁	Mg ₂	Mg ₃	Mean		Mg ₁	Mg ₂	Mg ₃	Mean	
P ₁ P ₂ P ₃	(±0.04)					(±0.05)					(±0.03)					(±0.08)				
	1.4	1.2	0.9	1.2		1.6	1.3	1.1	1.3		1.3	1.0	0.8	1.0		1.7	1.3	1.2	1.4	
	1.4	1.2	0.9	1.1		1.7	1.3	0.9	1.3		1.3	1.0	0.8	1.0		1.9	1.6	1.3	1.6	
Sig. effects Linear Quadratic Overall	1.4	1.1	1.0	1.2		1.8	1.4	1.1	1.4		1.5	1.1	0.9	1.2		1.9	1.4	1.3	1.5	
	P < 0.05	P < 0.01				P < 0.05	P < 0.01				P < 0.05	P < 0.01				P < 0.05	P < 0.01			
		Mg, K					Mg, K					Mg, K, P,				P	Mg, K			
Sig. effects Linear Quadratic Overall	K	—					K				P	K				K				
											K × P					P				
							Mg, K, Mg × K				Mg, K, P, Mg × K					Mg, K, K × P, Mg × K				

(continued from opposite)

June 2nd Whorl					July Top Whorl					October Top Whorl					October 2nd Whorl					Level				
K ₁	K ₂	K ₃	Mean		K ₁	K ₂	K ₃	Mean		K ₁	K ₂	K ₃	Mean		K ₁	K ₂	K ₃	Mean						
(±0.06)					(±0.08)					(±0.04)					(±0.11)					(±0.06)				
1.1	1.7	2.6	1.8		1.3	1.9	2.8	2.0		1.4	2.0	2.9	2.1		1.2	1.8	2.6	1.9						
0.8	1.3	2.1	1.4		1.1	1.6	2.2	1.6		1.2	1.4	2.1	1.5		0.9	1.2	1.9	1.4						
0.8	1.0	1.8	1.2		1.1	1.4	1.9	1.4		1.1	1.3	1.9	1.4		0.8	1.0	1.3	1.0						
P ₁	P ₂	P ₃	Mean		P ₁	P ₂	P ₃	Mean		P ₁	P ₂	P ₃	Mean		P ₁	P ₂	P ₃	Mean						
(±0.06)					(±0.08)					(±0.04)					(±0.11)					(±0.06)				
0.9	0.9	0.9	0.9		1.2	1.1	1.2	1.2		1.2	1.3	1.2	1.2		1.0	1.0	1.0	1.0						
1.2	1.4	1.4	1.3		1.5	1.7	1.7	1.6		1.6	1.4	1.7	1.6		1.3	1.2	1.5	1.4						
1.9	2.2	2.4	2.2		2.1	2.4	2.4	2.3		2.1	2.2	2.5	2.3		1.9	2.0	2.0	2.0						
Mg ₁	Mg ₂	Mg ₃	Mean		Mg ₁	Mg ₂	Mg ₃	Mean		Mg ₁	Mg ₂	Mg ₃	Mean		Mg ₁	Mg ₂	Mg ₃	Mean						
(±0.06)					(±0.08)					(±0.04)					(±0.11)					(±0.06)				
1.7	1.2	1.1	1.3		1.8	1.7	1.4	1.6		2.0	1.5	1.4	1.6		1.8	1.3	1.1	1.4						
1.8	1.5	1.2	1.5		2.1	1.7	1.4	1.7		2.1	1.6	1.2	1.6		1.8	1.3	1.0	1.4						
1.9	1.5	1.3	1.6		2.2	1.6	1.5	1.8		2.2	1.5	1.7	1.8		2.1	1.5	1.0	1.5						
P < 0.05			P < 0.01		P < 0.05			P < 0.01		P < 0.05			P < 0.01		P < 0.05			P < 0.01						
			Mg, K, P		P			Mg, K					Mg, K					Mg, K						
			Mg, K		—			—		K			Mg		K			—						
			Mg, K, P, Mg × K, K × P		P, Mg × P			Mg, K, Mg × K		Mg × K			Mg, K					Mg, K, Mg × K						

TABLE VI: CONCENTRATION OF PHOSPHORUS IN LAMINA
% P in dry lamina

(continued opposite)

Level	April 2nd Whorl				May 2nd Whorl				May 3rd Whorl				June Top Whorl			
	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean
Mg ₁	(±0.008)				(±0.007)				(±0.008)				(±0.007)			
	.26	.26	.26	.26	.20	.21	.20	.20	.22	.23	.20	.22	.26	.26	.24	.25
	.24	.24	.24	.24	.19	.19	.18	.19	.21	.22	.20	.21	.25	.25	.23	.24
Mg ₃	.23	.24	.24	.24	.19	.20	.18	.19	.21	.22	.20	.21	.25	.23	.26	.25
Level	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean
K ₁	(±0.008)				(±0.007)				(±0.008)				(±0.007)			
	.22	.23	.28	.24	.16	.18	.23	.19	.18	.19	.27	.21	.16	.24	.36	.25
	.21	.24	.29	.25	.17	.18	.24	.20	.18	.20	.28	.22	.14	.23	.37	.25
K ₃	.22	.24	.27	.24	.16	.18	.21	.18	.17	.19	.25	.20	.15	.24	.34	.24
Level	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean
P ₁	(±0.008)				(±0.007)				(±0.008)				(±0.007)			
	.22	.21	.22	.22	.18	.16	.16	.16	.18	.18	.18	.18	.16	.15	.14	.15
	.24	.24	.22	.24	.18	.19	.18	.18	.19	.19	.20	.19	.24	.23	.23	.24
P ₃	.30	.28	.27	.28	.25	.22	.22	.23	.28	.26	.26	.27	.35	.34	.38	.36
Sig. effects	P < 0.05				P < 0.05				P < 0.05				P < 0.05			
Linear																
Quadratic	P				K, P				K, P							
Overall	Mg				Mg, K				K, P				Mg × K			
	P				P				K, P				P, Mg × P			

(continued from opposite)

June 2nd Whorl				July Top Whorl				October Top Whorl				October 2nd Whorl				Level
K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	
(±0.009)				(±0.014)				(±0.033)				(±0.017)				(±0.010)
.22	.21	.21	.22	.26	.25	.26	.26	.27	.22	.25	.25	.23	.22	.23	.22	Mg ₁
.20	.22	.22	.22	.26	.25	.29	.27	.27	.25	.26	.26	.24	.24	.29	.25	Mg ₂
.23	.22	.22	.22	.28	.26	.27	.27	.30	.27	.28	.28	.31	.24	.22	.26	Mg ₃
P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	Level
(±0.009)				(±0.014)				(±0.033)				(±0.017)				(±0.010)
.13	.20	.32	.22	.17	.25	.38	.27	.21	.27	.37	.28	.17	.22	.39	.26	K ₁
.13	.20	.31	.22	.18	.26	.32	.25	.18	.22	.34	.25	.17	.20	.32	.23	K ₂
.14	.20	.30	.22	.24	.25	.33	.27	.20	.24	.35	.26	.18	.21	.36	.25	K ₃
Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Level
(±0.009)				(±0.014)				(±0.033)				(±0.017)				(±0.010)
.14	.13	.13	.13	.18	.23	.18	.20	.20	.19	.20	.20	.17	.17	.17	.17	P ₁
.20	.20	.21	.20	.26	.24	.26	.25	.26	.24	.23	.24	.20	.22	.20	.21	P ₂
.31	.31	.32	.31	.33	.33	.37	.34	.29	.34	.42	.35	.30	.37	.40	.36	P ₃
P < 0.05	P < 0.01			P < 0.05	P < 0.01			P < 0.05	P < 0.01			P < 0.05	P < 0.01			Sig. effects
	P				P				P			Mg	P			Linear
	P				—				—				P			Quadratic
	P			Mg × P	P, K × P				P			Mg, Mg × K, Mg × P			P	Overall

TABLE VII: CONCENTRATION OF MANGANESE IN LAMINA
p.p.m. Mn in dry lamina

(continued opposite)

Level	April 2nd Whorl				May 2nd Whorl				May 3rd Whorl				June Top Whorl			
	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean
Mg ₁ Mg ₂ Mg ₃	(±1.6)				(±3.2)				(±1.9)				(±1.0)			
	(±0.9)				(±1.8)				(±3.0)				(±1.7)			
	24	26	30	27	17	18	23	19	27	33	31	30	28	34	44	35
	24	29	28	27	22	16	21	20	28	28	33	30	24	21	26	24
Level	26	23	25	24	17	15	16	16	29	26	25	27	21	21	23	22
	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean
	(±1.6)				(±3.2)				(±1.9)				(±1.0)			
	(±0.9)				(±1.8)				(±3.0)				(±1.7)			
K ₁	22	26	26	25	20	14	21	18	24	28	32	28	19	20	34	24
K ₂	24	27	27	26	14	17	18	17	24	30	32	29	20	20	35	25
K ₃	27	28	28	28	17	19	23	20	28	30	32	30	25	26	42	31
Level	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean
	(±1.6)				(±3.2)				(±1.9)				(±1.0)			
	(±0.9)				(±1.8)				(±3.0)				(±1.7)			
	25	25	23	24	17	21	14	17	29	25	22	25	28	19	18	21
P ₁	27	29	25	27	16	17	17	17	30	30	29	29	23	23	19	22
P ₂	29	28	25	27	25	21	17	21	32	34	30	32	54	29	28	37
Sig. effects	P < 0.05				P < 0.05				P < 0.01				P < 0.05			
	P				—				—				P < 0.01			
	—				—				Mg				K			
	—				—				—				Mg			
Overall	—				—				Mg × K				K			
	—				—				—				Mg, P, Mg × P			

June 2nd Whorl				July Top Whorl				October Top Whorl				October 2nd Whorl				Level	
K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean	K ₁	K ₂	K ₃	Mean		
(±3.4)				(±3.5)				(±2.0)				(±1.8)				Mg ₁	
32	42	53	42	26	25	51	34	19	21	30	23	26	38	51	38		
25	25	28	26	19	25	26	23	15	14	18	16	22	19	27	22		
22	23	24	23	24	19	20	21	16	18	18	17	22	20	28	23		
P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	P ₁	P ₂	P ₃	Mean	Level	
(±3.4)				(±3.5)				(±2.0)				(±1.8)					K ₁
18	19	42	26	17	19	33	23	15	15	20	17	18	17	35	23		
19	23	49	30	18	16	35	23	15	16	22	18	20	24	33	26	K ₂	
27	28	49	35	21	30	46	32	16	18	31	22	31	25	49	35		K ₃
Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Mg ₁	Mg ₂	Mg ₃	Mean	Level	
(±3.4)				(±3.5)				(±2.0)				(±1.8)					P ₁
29	19	16	21	20	18	18	18	19	12	14	15	32	20	17	23		
24	25	21	23	28	18	18	22	20	14	15	17	30	17	19	22	P ₃	
74	34	32	47	54	33	27	38	30	20	23	24	53	29	34	39		
P < 0.05	P < 0.01			P < 0.05	P < 0.01			P < 0.05	P < 0.01			P < 0.05	P < 0.01				Sig. effects
				Mg, K, P				Mg, K, P				Mg, K, P				Linear	
Mg				P				Mg, P				Mg, P				Quadratic	
K	Mg, P, Mg × P			Mg × P				Mg × K, K × P				Mg × K				Overall	

well defined were slight and never exceeded 5 per cent of the original amount of the element present in the ungerminated seed; full results are not presented here.

MAGNESIUM, TABLE IV—The concentration of magnesium in the laminae increased with magnesium and decreased with potassium levels; both effects were highly significant, that of potassium being predominantly linear. Increased magnesium supply was most effective in increasing magnesium content at the K_1 or P_2 and P_3 levels (significant MgK, MgP interactions). The effect of increased phosphate supply was to give an increase in magnesium content at the Mg_3 level. This effect, which was largely responsible for the overall response to phosphate, was sometimes significant.

POTASSIUM, TABLE V—The concentration of potassium in the laminae increased with potassium and decreased with magnesium levels; both effects were highly significant, that of magnesium being predominantly linear. Potassium addition was always more effective in increasing the potassium content at the lowest magnesium level (significant MgK interaction). Increased phosphate supply gave an overall increase in potassium concentration; this response was usually significant and was mainly contributed to by the K_3 treatments (significant KP interaction noted in May and June).

PHOSPHORUS, TABLE VI—Increased phosphate supply significantly increased the phosphorus concentration in the laminae; this effect was more marked in the K_1 treatments but only in July was the KP interaction found to be significant. At the earlier samplings (April, May) increased magnesium supply produced significant reductions in the phosphorus content of the second whorl laminae but later this effect was reversed. The effect of potassium supply on phosphorus content was not consistent.

MANGANESE, TABLE VII—The concentration of manganese in the laminae showed well marked changes due to nutrient level; these effects first became obvious in May and persisted until the end of the experiment. Increased magnesium level decreased the manganese content of the laminae whereas increased supplies of either potassium or phosphate increased it; these effects were highly significant. The positive effects of potassium and phosphate on manganese content were much more pronounced at the Mg_1 level; this resulted in significant MgK and MgP interactions.

DISCUSSION

The main objective of this investigation was to examine the nature and importance of the interrelationships of magnesium and phosphorus in *Hevea brasiliensis*. It was found that magnesium addition at first reduced the concentration of phosphorus in the lamina but later increased it; phosphate addition frequently enhanced the magnesium concentration of the laminae at higher magnesium levels.

In addition to this direct effect of one exerted upon the other they both influenced the concentration of potassium in the lamina; thus increased magnesium supply invariably decreased the potassium concentration whereas increased phosphate supply increased it at the higher potassium levels. The opposing nature of magnesium and phosphate was also revealed in their effect on the concentrations of manganese and, to a lesser extent, chlorophyll in the lamina. Thus increased magnesium supply decreased the concentration of manganese and increased that of chlorophyll whereas increased phosphate supply increased the manganese and decreased the chlorophyll concentrations.

A relationship between the effects of magnesium and phosphorus in the nutrition of *Hevea brasiliensis* was therefore demonstrated. As observed on page 232 the inverse nature of the interrelationship between magnesium and potassium in both *Hevea brasiliensis* and other crops has been well established. The beneficial effect of magnesium on phosphate uptake has also been reported by some authors (ZIMMERMAN, 1947 and *loc. cit.*). The detrimental effect of magnesium addition on manganese accumulation has not, however, been reported in the general literature, although the beneficial influence of potassium addition on manganese uptake has been noted (YORK, BRADFIELD and PEECH 1954). On the other hand BEAUFILS (1954) claimed that magnesium and manganese were positively correlated with one another. It is possible that the effects of the interrelationship of magnesium and manganese may be of considerable importance in the cultivation of *Hevea brasiliensis* in Malaya where the strongly acidic nature of the soils may well be conducive to the production of both magnesium deficiency and manganese toxicity effects (MULDER and GERRETSEN 1952).

The total dry weight of the plant showed distinct variations with treatment. The response to increased potassium supply was an overall decrease in dry weight but the response to magnesium and phosphate addition changed with time. These changes, which may need subsequent confirmation, were correlated with corresponding changes in the vigour of the plants and suggested that during the early stages growth was limited by the magnesium supply whereas, later, development became more dependent on an increased supply of phosphate. These effects may possibly have been contributed to by the fact that the proportion of magnesium translocated from the seed to the seedlings was less than that of potassium and phosphorus. A similar change in effect of magnesium and phosphate levels was also noted for the concentration of rubber in the stems and petioles.

The lack of consistency from month to month in the effects of nutrient level on rubber concentration was noteworthy. Frequently these effects were significant but the net increase in the concentration value was never large (not more than 25%). The relatively small magnitude of the differences obtained suggested that the concentration of rubber within the plant was not directly affected by the nutrient concentration but only the total amount produced per plant; this is substantially the same inference as

was drawn from a previous entirely independent investigation (BOLLE-JONES 1954b). This does not preclude the possibility of much larger differences being obtained if the analysis could be carried out on rubber bearing tissues only.

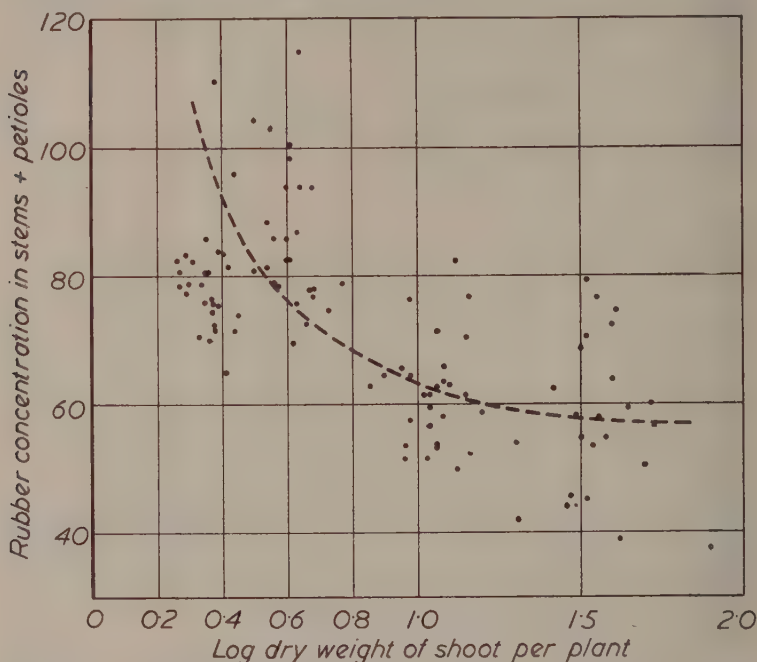


Figure 5. Decline in concentration of rubber in bulked stems and petioles with increasing dry weight of shoot per plant. Rubber concentration expressed as mg per 5 gm of tissue; dry weight given as logarithm of dry weight in grams. Each point represents mean of two replicates. Data based on samplings taken April, May, June and October.

The gradual decrease in concentration of rubber with increasing age of the plant was probably due to the increasing proportion of tissues not bearing rubber. Thus the dry weight of the shoot appeared to be inversely related to the concentration of rubber (Figure 5). Where only the 'green' part of the stems was bulked with the petioles for analysis (TABLE II, July) the concentration of rubber was appreciably higher than where no such differentiation between green and brown stem was made (June).

The visual observation that increased phosphate supply accentuated the severity of magnesium deficiency symptoms at the Mg_1 level was not confirmed by a resultant lower magnesium concentration in the laminae. The K/Mg ratio values however showed marked increases in the laminae of the Mg_1K_3 plants

due to increased phosphate supply (TABLE VIII) ; this trend which was most marked in the older whorls was also obvious in the second whorl of the Mg_1K_2 plants. High K/Mg ratio values were found where magnesium deficiency symptoms were obvious. In general these ratio values seemed to furnish a better guide than the concentration of magnesium to the occurrence of magnesium deficiency symptoms.

TABLE VIII: VARIATION OF K/Mg RATIO IN LAMINA WITH P LEVEL IN THE Mg_1 PLANTS

		Level	K ₁	K ₂	K ₃	Mean
Top whorl — means of July and October values		P ₁	10	16	19	15
		P ₂	10	14	23	16
		P ₃	11	17	30	20
		Mean	10	16	24	17
		Level	K ₁	K ₂	K ₃	Mean
Second whorl — means of June and October values		P ₁	14	38	120	57
		P ₂	18	43	157	73
		P ₃	19	59	164	81
		Mean	17	46	147	70

The differential effect of increased phosphate supply on magnesium nutrition according to the level of magnesium supply (which resulted in a higher magnesium concentration at the higher Mg levels and increased severity of magnesium deficiency symptoms at the Mg_1 level) may explain why some authors have stated that added phosphate increased the magnesium content while others reported that it produced magnesium deficiency (*loc. cit.*). It is probable that in such studies the effect of phosphate on K/Mg ratio values (and not on magnesium concentration) would have yielded a better interpretation of the effects observed.

The practical significance of the results which have emerged from this investigation may be summarized as follows:

- (a) Heavy applications of phosphate in regions known to bear plants with magnesium deficient foliage may accentuate the severity of the deficiency. This supposition is independently supported by MULDER's

- (1952) investigations on the nutrition of fruit trees from which he concluded that to increase the phosphorus content of apple leaves in magnesium deficient areas it was more economical to apply magnesium-containing rather than phosphorus-containing fertilisers.
- (b) The potassium requirement of *Hevea brasiliensis* may be low, as comparatively small concentrations of potassium in the nutrient frequently decreased the dry weight of the plant; a similar low requirement for potassium and the latter's adverse effect on girth increment has been noted in the annual report of the Soils Division for 1951. Hence routine applications of potassium to *Hevea* crops should be in small amounts and only when necessary. The incidence of potassium deficiency symptoms in Malaya has not yet been demonstrated.
- (c) For diagnostic and advisory purposes it is better, when examining leaves suspected of being incipiently deficient in magnesium, to evaluate and compare the K/Mg ratio values with those of healthy laminae rather than to depend solely on the concentration of magnesium as the decisive criterion.

It is recognised that the above points are based entirely on investigations carried out on young seedlings but until there is evidence to show that mature trees may react differently it would appear wiser to adhere to those recommendations.

SUMMARY

Hevea brasiliensis seedlings, clone Tjirandji 1, were grown in pot sand culture in a 3³ factorial experiment in which magnesium, potassium and phosphate were each applied at deficiency, sufficiency and luxury levels of consumption.

In the earlier stages growth appeared to be more dependent on an adequate supply of magnesium than on phosphate; later this effect was reversed. Most of the effects on dry weight of plant, rubber and chlorophyll contents of the laminae were explicable on this basis.

The variation with nutrient level of the rubber concentration in bulked stem and petiole tissues was small, but potassium or phosphate addition gave positive and magnesium gave negative responses during early growth. These effects were inversely related to the dry weight trends and suggested a 'dilution' effect of non rubber bearing tissue on the rubber concentration values obtained.

Low magnesium supply or excessive amounts of potassium or phosphate (at the lowest magnesium level) produced severe magnesium deficiency symptoms which were associated with an elevated K/Mg ratio.

Evidence in support of a direct interrelationship between magnesium and phosphorus was presented: the levels of magnesium and phosphate supplied influenced the concentration of phosphorus and magnesium respectively in the lamina. The con-

centration of magnesium in the lamina was governed by the relative levels of magnesium and potassium and of magnesium and phosphate supplied to the plant while the concentration of phosphorus was determined by the relative levels of magnesium and phosphate.

An indirect relationship of magnesium and phosphate was reflected in their respective effects, usually opposite, on the chlorophyll and potassium concentrations in the lamina.

The close interrelationship of the three nutrients examined was illustrated in their effect on manganese concentration: increased magnesium level decreased while increased potassium or phosphate level increased the manganese concentration in the lamina. Attention was drawn to points of practical significance arising from the results.

I am indebted to Mr D.K. Dutta Ray for the numerous statistical computations which this investigation necessitated.

Soils Division
Rubber Research Institute of Malaya
Kuala Lumpur

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NUTRITION OF HEVEA BRASILIENSIS

IV. INTERCLONAL AND SEASONAL VARIATION IN COMPOSITION OF LEAVES

By

E.W. BOLLE-JONES AND K. RATNASINGAM

Leaves were sampled at intervals, over a period of a year, from clones Tjir 1, PB 86 and RRIM 501 and analysed. The petiolar rubber concentration and the laminar concentrations of chlorophyll, ash, nitrogen, phosphorus, magnesium, potassium, calcium and iron varied according to clone. Increasing age of leaf increased the petiolar concentration of rubber and the laminar concentrations of chlorophyll, ash, calcium, iron and manganese but decreased the laminar concentrations of nitrogen, phosphorus and potassium. The month of sampling affected markedly the concentration of each variable examined and significantly influenced the effect of whorl position (or age of leaf) on the concentrations of rubber, chlorophyll, phosphorus and calcium found. The effect of month of sampling on the laminar chlorophyll and calcium concentrations also varied with clone. Rainfall was partly responsible for the seasonal variation encountered in the rubber, nitrogen and iron concentrations.

The petiolar rubber concentration varied according to the laminar nitrogen concentration, which, in turn, was influenced by the calcium concentration present.

The present day diversity of hevea clones has arisen by selection and breeding from a relatively small number of plants produced from seeds collected in Brazil by Sir H.A. Wickam (BAPTIST 1953). This limited basis for selection has given rise to some clones which differ greatly in yield of rubber per tree although they may be of similar vigour and not always easily distinguishable by their vegetative characteristics. On the other hand there are clones which may be easily distinguished from one another but produce rubber yields of the same magnitude. These general considerations together with indications from field experiments (see annual report of this institute for 1953) that differential responses to nitrogen, phosphorus or potassium application, according to clone, are not obtained has led to a policy of formulating manurial programmes regardless of the clone involved. This policy gains general acceptance for (unlike many other vegetatively propagated crops) there is no published evidence to indicate that the choice of stock, usually an unselected seedling, exerts a marked influence on the mineral nutrition of the clonal scion.

The object of this investigation was to obtain evidence that the concentrations of rubber, chlorophyll and minerals in the foliage, varied with clone, whorl position and season. This evidence was obtained by the examination of the chlorophyll and mineral composition of the laminae and the concentration of rubber in the petioles, taken from varying whorl positions, of three different clones at intervals over a twelve month period. The three high yielding clones chosen, namely Tjirandji 1, Prang Besar 86, and RRIM 501 are representative of those widely grown at present in Malaya.

If the results of this investigation indicated that the mineral composition did not vary according to clone this would confirm the general assumption that the mineral requirement of each clone is roughly similar. If however the composition varied markedly with clone then this general assumption might be doubted and it would suggest that the level of mineral requirement varied according to clone. Information was also needed upon which field sampling procedures could be based and which could serve as a guide to advisory practice.

The effect of the vegetative cycle on the mineral composition of the foliage has also been described by BEAUFILS (1954) who investigated the leaves taken from mature trees of clone Dj 1. He concluded that there was a similarity in the seasonal variation of nitrogen, phosphorus and potassium, which was different from that of calcium; the maximum values for nitrogen, phosphorus and potassium were obtained at the beginning of the vegetative cycle and thereafter decreased gradually until the commencement of 'wintering'. The calcium content of the leaves increased progressively with time.

EXPERIMENTAL

The three clones, Tjir 1, PB 86 and RRIM 501 were grown in a nursery at the Rubber Research Institute Experiment Station in adjacent blocks, each of which was approximately 60 ft $\times$ 60 ft in area and contained the same number of plants (140). The soil was of a light sandy nature in which clones Tjir 1 and RRIM 501 usually grow more vigorously than clone PB 86. The unselected seedlings were planted in February 1949 and given a complete fertiliser dressing containing nitrogen, phosphorus and potassium in July 1949; they were budded with the respective clone in August 1950 and cut back to union level in September 1950. In January 1953 the shoots were again cut back and the first leaf sampling for analysis in this investigation was taken on 20 May and thereafter on each of the subsequent dates: 16 June, 16 July, 25 August, 22 September, 27 October, 8 December, 13 January, 1954, 16 February, 16 March, 19 April and 24 May. Each tree was kept rigorously pruned to prevent the establishment of lateral branches.

At each sampling date three trees, representative of each clonal area, were selected and, for the sake of convenience, were designated A, B and C. Each of these trees bore a quiescent

terminal bud and a fully expanded uppermost whorl of leaves; the uppermost whorl was designated as the top whorl and the two successive lower ones as the second and third whorls respectively. All leaves at the top, second and third whorl positions respectively were removed from trees *A*, *B* and *C*. This procedure yielded nine samples per clone and a total of twentyseven leaf samples at any one sampling date. The samples were taken between 8.00 and 10.00 hours; a tree once sampled on one of the above dates was not further sampled during the course of this investigation. For each sample the petioles were separated from the laminae, dried, milled and their rubber concentration estimated. The midribs were excised from the laminae and discarded; a sub-sample of the fresh laminae was taken for chlorophyll estimation and the remainder dried and analysed for nitrogen, phosphorus, magnesium, potassium, calcium, iron and manganese. The ash concentration in the dried laminar material was also estimated. The chemical methods employed have been described (BOLLE-JONES 1954a).

RESULTS

The full data obtained during this investigation are deposited in the research archives of the R.R.I. of Malaya (RRIM Document 1). For one of the variables examined, namely rubber concentration, the analysis of variance is given in TABLE I in order that the partitioning of the degrees of freedom may be illustrated. In addition there are presented:

- i 2-way mean tables which illustrate the effect of clone or whorl position on each variable; the respective standard error is included within each table.
- ii Graphs which indicate the variation with time of the mean concentration, regardless of whorl, of each variable for each clone; the least significant difference between monthly clone means, at the 5% level of significance, is shown on each graph.
- iii Graphs which show the variation with time of the mean concentration, regardless of clone, of each variable for each whorl position; the least significant difference between monthly whorl means, at the 5% level of significance, is shown on each graph.

THE CONCENTRATION OF RUBBER IN THE PETIOLE

The overall differences between clones, regardless of whorls, were significant at the 0.1% level and showed that the Tjir 1 petioles contained the highest and PB 86 the lowest concentration of rubber in the tissues (TABLE II, *Figure 1*). This difference, which was large, was least marked in the third whorl petioles (TABLE II, significant clones $\times$ whorls interaction, $P < 0.05$). The mean rubber concentration of each clone for different sampling dates (*Figure 1*) showed that for each clone a depression in concentration usually occurred between July and October and between February and May.

TABLE I: EFFECT OF CLONES, WHORL POSITION, AND MONTHS (OR DATES OF SAMPLING) ON THE PETIOLAR RUBBER CONCENTRATION
ANALYSIS OF VARIANCE

(Rubber expressed as mg/5 gm dry petioles)

Source	d.f.	Mean square	P <
1. Clones	2	54,936.8	0.001
2. Whorls	2	5,055.6	0.001
3. Months	11	3,909.3	0.001
4. Clones $\times$ whorls	4	1,257.4	0.05
5. Clones $\times$ months	22	612.8	not sig.
6. Whorls $\times$ months	22	691.8	0.05
7. Clones $\times$ whorls $\times$ months	44	169.7	not sig.
8. Trees within months and clones	72	362.0	
9. (Trees $\times$ whorls) within months and clones	144	271.1	

If in the analysis of variance for any variable the mean square value obtained for source (8) was found to be significant when compared against the mean square for source (9) - as for rubber, shown above - then the mean square obtained for source (8) was regarded as the error term. If, on the other hand, the mean square for source (8) was found to be not significant then both sources (8) and (9) were combined to give an error term with 216 degrees of freedom.

TABLE II: EFFECT OF CLONE AND WHORL POSITION ON RUBBER CONCENTRATION
Rubber expressed as mg/5 gm dry petiole. Mean values

Clone \ Whorl	Top	2nd	3rd	Mean
		(± 3.2)		(± 1.8)
Tjir 1	118	134	132	128
PB 86	74	83	96	84
RRIM 501	92	98	95	95
Mean	94	105	108	102
		(± 1.8)		

The second and third whorl petioles possessed a significantly higher rubber concentration than those of the top whorl for clones PB 86 and Tjir 1; a similar difference was obvious for clone RRIM 501 but did not achieve significance (TABLE II).

The effect of whorl position on rubber concentration became less marked towards the end of the investigation (Figure 2); the whorls $\times$ months interaction was significant at the 5% level. The two seasonal depressions in concentration, noted above, were observed for each whorl.

THE CONCENTRATION OF CHLOROPHYLL IN THE LAMINA

Clones Tjir 1 and RRIM 501 did not differ significantly from one another in regard to chlorophyll, but both contained a significantly higher ($P < 0.001$) concentration than did PB 86,

TABLE III: EFFECT OF CLONE AND WHORL POSITION ON CHLOROPHYLL
CONCENTRATION

Chlorophyll expressed as mg/gm dry lamina. Mean values

Clone \ Whorl	Top	2nd	3rd	Mean
	(± 0.11)			(± 0.06)
Tjir 1	5.8	6.5	7.0	6.5
PB 86	4.4	5.0	5.2	4.8
RRIM 501	5.6	6.5	6.9	6.4
Mean	5.3	6.0	6.4	5.9
	(± 0.06)			

TABLE IV: EFFECT OF CLONE AND WHORL POSITION ON ASH CONCENTRATION

Ash expressed as % of dry lamina. Mean values

Clone \ Whorl	Top	2nd	3rd	Mean
	(± 0.15)			(± 0.09)
Tjir 1	4.2	4.4	4.8	4.4
PB 86	3.6	4.0	4.4	4.0
RRIM 501	3.4	3.5	3.9	3.6
Mean	3.7	4.0	4.4	4.0
	(± 0.09)			

(TABLE III, *Figure 3*). The variation of chlorophyll concentration with time was fairly similar for clones Tjir 1 and RRIM 501 (*Figure 3*); clone PB 86 did not conform to the same pattern during the period, August to December. This resulted in a significant ($P < 0.05$) clones $\times$ months interaction. For all three clones examined the chlorophyll concentration was low in August.

The third whorl laminae contained a higher concentration of chlorophyll than did those of the second whorl which, in turn, was higher than that of the top whorl (TABLE III). The overall differences between whorls were highly significant ($P < 0.001$). The overall trends were individually applicable to Tjir 1 and RRIM 501 but for PB 86 the difference, in chlorophyll concentration between second and third whorl laminae was not significant.

First and second whorl laminae showed a broad similarity between the variations of chlorophyll concentration with time (*Figure 4*) whereas the third whorl laminae showed a dissimilar trend towards the latter end of the investigation. This resulted in a highly significant ($P < 0.001$) interaction between whorls and months.

THE CONCENTRATION OF ASH IN THE LAMINA

The concentration of ash in the laminae of clone Tjir 1 was much higher than that of PB 86 which in turn was significantly higher than that of clone RRIM 501 (TABLE IV). For clones Tjir 1 and RRIM 501 the ash concentration generally increased with time (*Figure 5*) although an initial decline was recorded.

The concentration of ash found in the third whorl laminae was significantly higher ($P < 0.01$) than for those of the top and second whorls (TABLE IV). The ash concentration of each whorl showed a marked decline in June and thereafter an overall increase with time (*Figure 6*).

THE CONCENTRATION OF NITROGEN IN THE LAMINA

The nitrogen concentration of clones Tjir 1 and RRIM 501 were closely similar and significantly higher ($P < 0.001$) than that of clone PB 86 (TABLE V, *Figure 7*). Clones Tjir 1 and RRIM 501 showed depressions in nitrogen concentration between June and September and in March (*Figure 7*); a similar decline was observed both in July and October for the laminae of PB 86.

The nitrogen concentration of the third whorl laminae was significantly less ($P < 0.01$) than those of either top or second whorl (TABLE V); the second whorl laminae usually contained less nitrogen than those of the top whorl but this difference was not significant. The top and second whorl laminae showed a similar variation of nitrogen concentration with time (*Figure 8*).

THE CONCENTRATION OF PHOSPHORUS IN THE LAMINA

Clone Tjir 1 possessed a significantly higher laminar phosphorus concentration than either clone PB 86 or RRIM 501 which

were of approximately equal value (TABLE VI). The variation of phosphorus concentration with time was generally slight and was mainly notable for the sharp rise, obtained for all three clones, in February, (Figure 9).

For all clones the top whorl laminae possessed a significantly higher ($P < 0.001$) concentration of phosphorus than the second whorl which, in turn, was higher than that of the third whorl for clones PB 86 and RRIM 501 (TABLE VI). Laminae taken from different whorl positions did not show the same variation in phosphorus concentration with time (Figure 10); the interaction between whorls and months was significant at the 1% level.

TABLE V: EFFECT OF CLONE AND WHORL POSITION ON NITROGEN CONCENTRATION

Nitrogen expressed as % of dry lamina. Mean values

Clone \ Whorl	Top	2nd	3rd	Mean
	(± 0.040)			(± 0.023)
<i>Tjir 1</i>	3.39	3.33	3.24	3.32
<i>PE 86</i>	3.14	3.10	2.97	3.07
<i>RRIM 501</i>	3.39	3.34	3.25	3.33
<i>Mean</i>	3.30	3.26	3.15	3.24
	(± 0.023)			

TABLE VI: EFFECT OF CLONE AND WHORL POSITION ON PHOSPHORUS CONCENTRATION

Phosphorus expressed as % of dry lamina. Mean values

Clone \ Whorl	Top	2nd	3rd	Mean
	(± 0.0033)			(± 0.0019)
<i>Tjir 1</i>	0.214	0.183	0.180	0.192
<i>PB 86</i>	0.208	0.176	0.165	0.183
<i>RRIM 501</i>	0.210	0.179	0.166	0.185
<i>Mean</i>	0.211	0.179	0.170	0.187
	(± 0.0019)			

THE CONCENTRATION OF MAGNESIUM IN THE LAMINA

As for all other variables examined, with the exception of manganese, during this investigation the magnesium concentration varied with clone. Clone Tjir 1 possessed a significantly higher ($P < 0.001$) concentration than either PB 86 or RRIM 501 which were both approximately similar (TABLE VII). Each clone was distinguished by the occurrence of an extremely low magnesium concentration at the December sampling (*Figure 11*).

The difference between whorl concentrations were not significant although the top whorl usually showed a higher magnesium concentration than the second or third whorl laminae (TABLE VII).

TABLE VII: EFFECT OF CLONE AND WHORL POSITION ON MAGNESIUM
CONCENTRATION

Magnesium expressed as % of dry lamina. Mean values

Clone \ Whorl	Top	2nd	3rd	Mean
	(± 0.010)			(± 0.006)
<i>Tjir 1</i>	0.18	0.16	0.16	0.17
<i>PB 86</i>	0.13	0.12	0.12	0.12
<i>RRIM 501</i>	0.13	0.12	0.13	0.13
<i>Mean</i>	0.15	0.13	0.14	0.14
	(± 0.006)			

TABLE VIII: EFFECT OF CLONE AND WHORL POSITION ON POTASSIUM
CONCENTRATION

Potassium expressed as % of dry lamina. Mean values

Clone \ Whorl	Top	2nd	3rd	Mean
	(± 0.044)			(± 0.026)
<i>Tjir 1</i>	1.16	1.04	0.91	1.04
<i>PB 86</i>	1.10	1.05	0.96	1.04
<i>RRIM 501</i>	1.02	0.91	0.80	0.91
<i>Mean</i>	1.10	1.00	0.89	0.99
	(± 0.026)			

The pattern of variation of magnesium concentration with time was similar for all whorls (*Figure 12*) and again illustrated the marked depression in magnesium concentration at the December sampling.

THE CONCENTRATION OF POTASSIUM IN THE LAMINA

Clone RRIM 501 possessed a significantly lower ($P < 0.01$) potassium concentration than either clone PB 86 or Tjir 1 both of which were of similar concentration (TABLE VIII). Clones Tjir 1 and RRIM 501 showed a similar pattern of seasonal variation of potassium concentration (*Figure 13*); clone PB 86 followed a similar trend until the September sampling but differed markedly thereafter.

The top whorl laminae possessed a significantly higher concentration of potassium than did the second whorl which in turn possessed a higher concentration than the third whorl laminae (TABLE VIII). The variation of potassium concentration with time was similar for each whorl and the differences between whorls became more marked with time (*Figure 14*).

THE CONCENTRATION OF CALCIUM IN THE LAMINA

The calcium concentration found in the laminae of clone Tjir 1 was significantly higher ($P < 0.001$) than that of either clone PB 86 or RRIM 501 which did not differ significantly from one another (TABLE IX). Clones Tjir 1 and RRIM 501 showed an overall increase of laminar calcium concentration with time; this trend was less defined in PB 86 laminae which possessed a notably high concentration in September and October (*Figure 15*). The interaction between clones and months was highly significant ($P < 0.001$).

The top whorl laminae contained a significantly lower ($P < 0.001$) concentration of calcium than did the second whorl laminae which in turn possessed a lower concentration than those of the third whorl (TABLE IX). The lower the whorl position the more marked was the trend to increase the laminar calcium concentration with time (*Figure 16*); the interaction between whorls and months was significant ($P < 0.01$).

THE CONCENTRATION OF IRON IN THE LAMINA

The laminae of clone PB 86 contained a significantly higher ($P < 0.05$) concentration of iron than did either clone Tjir 1 or RRIM 501 both of which were almost equal (TABLE X). All clones showed a definite depression in iron concentration between May and October (*Figure 17*).

The concentration of iron in the laminae increased with the age or position of the whorl (TABLE X, *Figure 18*); the third whorl laminae of clones PB 86 and Tjir 1 contained a significantly higher ($P < 0.05$) concentration than did those of the respective top whorl (TABLE X). All whorls varied in nearly the same

manner with time and there was no significant whorls $\times$ months interaction. All whorls showed a depression in iron concentration towards July (*Figure 18*).

THE CONCENTRATION OF MANGANESE IN THE LAMINA

Unlike all the other minerals estimated manganese did not vary significantly with clone (TABLE XI). For both clone PB 86 and RRIM 501 a distinct fall in concentration occurred between the July and August samplings and later, for all clones, at the January sampling (*Figure 19*). The effect of time (or months) on concentration was significant at the 5% level only; many of the successive sampling values did not differ significantly from one another (*Figure 19*).

TABLE IX: EFFECT OF CLONE AND WHORL POSITION ON CALCIUM
CONCENTRATION

Calcium expressed as % of dry lamina. Mean values

Clone \ Whorl				Mean
	Top	2nd	3rd	
	(± 0.042)			(± 0.024)
<i>Tjir 1</i>	0.57	0.79	1.00	0.79
<i>PB 86</i>	0.38	0.65	0.86	0.63
<i>RRIM 501</i>	0.36	0.59	0.84	0.60
<i>Mean</i>	0.44	0.67	0.90	0.67
	(± 0.024)			

TABLE X: EFFECT OF CLONE AND WHORL POSITION ON IRON
CONCENTRATION

Iron expressed as p.p.m. of dry lamina. Mean values

Clone \ Whorl				Mean
	Top	2nd	3rd	
	(± 2.8)			(± 1.6)
<i>Tjir 1</i>	65	68	74	69
<i>PB 86</i>	70	77	78	75
<i>RRIM 501</i>	65	68	72	68
<i>Mean</i>	67	71	75	71
	(± 1.6)			

The manganese concentration increased with the age of the leaf and both second and third whorl laminae contained a significantly higher concentration than did those of the top whorl (TABLE XI). The seasonal variation of manganese concentration included a well defined decline at both the June and January samplings which was apparent for the laminae of each whorl (Figure 20).

THE RATIO OF POTASSIUM TO MAGNESIUM
CONCENTRATION FOUND IN THE LAMINA

Clone Tjir 1 possessed a significantly lower ($P < 0.01$) laminar K/Mg ratio than PB 86; it was also lower than that

TABLE XI: EFFECT OF CLONE AND WHORL POSITION ON MANGANESE
CONCENTRATION

Manganese expressed as p.p.m. of dry lamina. Mean values

Clone \ Whorl				Mean
	Top	2nd	3rd	
		(± 3.1)		(± 1.8)
Tjir 1	28	32	36	32
PB 86	22	30	35	29
RRIM 501	23	30	33	29
Mean	24	30	35	30
		(± 1.8)		

TABLE XII: EFFECT OF CLONE AND WHORL POSITION ON THE LAMINAR RATIO
OF POTASSIUM TO MAGNESIUM CONCENTRATION

Mean values

Clone \ Whorl				Mean
	Top	2nd	3rd	
		(± 0.74)		(± 0.43)
Tjir 1	7.0	7.5	7.4	7.3
PB 86	8.7	9.7	10.1	9.5
RRIM 501	8.3	9.3	7.8	8.5
Mean	8.0	8.8	8.5	8.4
		(± 0.43)		

of clone RRIM 501 but this difference barely failed to achieve significance (TABLE XII). The seasonal variation of the K/Mg ratio for each clone revealed a sharp decline in value at the April sampling (Figure 21).

There was no significant difference between different whorls (TABLE XII) and the monthly variation of the ratio values followed a similar pattern for each whorl (Figure 22).

INTERRELATIONSHIPS

An inspection of Figures 1-22 readily revealed that a marked variation in rubber, chlorophyll and mineral contents occurred with time. Accordingly the variation in sunshine, humidity, temperature and rainfall values, taken over a similar period at the Rubber Research Institute Experiment Station, were studied for any similarity in seasonal trend. No similarity was obvious between the humidity or temperature values and any of the variables estimated but a marked similarity between some of the latter and the seasonal trends for rainfall was apparent. Unfortunately the sunshine records were not taken for the period August 1953-January 1954 and the possibility of an interrelationship between sunshine and the variables examined cannot be discounted.

The variation of rainfall with time is shown in Figure 23. When these rainfall values were plotted against the mean for each variable for each month (*i.e.* a mean based on 27 values) significant positive correlations with rubber, nitrogen and iron concentrations were obtained. The regression lines which interrelate: rubber concentration and rainfall, nitrogen concentration and rainfall, iron concentration and rainfall, are given in Figures 24, 25 and 26.

The concentration of rubber found in the petioles was also significantly and positively correlated with the concentration of nitrogen in the laminae (Figure 27). This correlation was significant at the 5% level when twelve pairs of values were considered ($r = 0.707$) but was significant at the 0.1% level when 108 pairs of values were examined ($r = 0.354$). In this latter evaluation three pairs of values for each clone (*i.e.* a pair for each whorl, derived from means of A, B and C) for each sampling date were considered.

The use of twelve pairs of values for the evaluation of the correlation coefficients eliminated the effect, if any, of clones and whorls and gave for each month a pair of values for *Hevea brasiliensis* irrespective of the clone and whorl involved. If a correlation was shown to exist between twelve such pairs then this association may have been due to the effect of months. The calculation of the residual covariances in which the effects of clones, whorls, and months were eliminated, was not attempted owing to the large amount of time involved.

The examination of other twelve pairs of variables revealed the following positive significant correlations:

- a* ash and calcium ($P < 0.001$, *Figure 28*),
- b* ash and manganese ($P < 0.001$, *Figure 29*),
- c* ash and magnesium ($P < 0.05$, *Figure 30*),
- d* manganese and calcium ($P < 0.01$, *Figure 31*),
- e* nitrogen and calcium ($P < 0.05$, *Figure 32*).

Although the association noted between pairs. (*a*), (*b*), (*c*) and (*d*) may conceivably have been due to the similarity of response of each member of a pair to months (or time) this was scarcely true for (*e*).

It was obviously of great interest to assess the significance of the interrelationships which existed between rubber concentration, rainfall, nitrogen and calcium concentrations. It was found (taking correlation coefficients of zero order into consideration) that:

- i* the regression of rubber on rainfall (ignoring other factors) accounted for 46% of the variation in the rubber concentration (*Figure 24*).
- ii* the regression of rubber on nitrogen (ignoring other factors) accounted for 50% of the variation in the rubber concentration (*Figure 27*).
- iii* the regression of rubber on calcium (ignoring other factors) accounted for 20% of the variation in the rubber concentration; ($r = +0.445$, 12 pairs of values, not significant).

When the joint regression of rubber on rainfall and nitrogen (but ignoring calcium) was considered it was found that these two variables accounted for 58% of the variation in the rubber concentration. As nitrogen alone accounted for 50% of this variation the introduction of the rainfall information accounted for a relatively small addition; this was because nitrogen and rainfall were directly correlated (*Figure 25*).

When the regression of rubber on rainfall, nitrogen and calcium together was considered it was found that the joint regression accounted for no more than 58% of the total variation in rubber concentration. Consequently the inclusion of calcium into the multiple regression effected no measureable improvement—due mainly to the correlation which existed between calcium and nitrogen (*Figure 32*).

DISCUSSION

The results of this investigation have established beyond reasonable doubt that the rubber concentration of the petioles, and the concentrations of chlorophyll, ash, nitrogen, phosphorus, magnesium, potassium, calcium and iron found in the laminae, varied according to clone. The sole exception to this rule was manganese for which no significant clonal variation was established. With the exception of nitrogen, potassium and iron the concentrations of the foliar constituents examined were highest for clone Tjir 1. According to recent results obtained by BEAUFILS

(1954) the composition of the foliage can be expected to influence the composition of the latex. Excessive accumulation of some mineral elements in the latex may be associated with mechanical instability and other undesirable properties. Thus, the knowledge that this accumulation may be associated with certain clones with a high foliar concentration of these elements, may prove to be a valuable guide to the selection and multiplication of clonal material suitable for commercial production.

Of more direct significance to the plant breeder however, is the knowledge that certain clones possess very different petiolar concentrations of rubber. If it can be shown that this petiolar rubber concentration of young plants is related to the rubber yielding capacity of the mature trees then the petiolar rubber concentration may be used as a means of selecting prospective high yielding clones; the simple method of rubber estimation employed in this investigation has been described (BOLLE-JONES 1954a) and is capable of such a large scale application. ASHPLANT (1928) has shown that the diameter of the latex vessels of the petiole was always smaller in the low yielding than in the high yielding trees. This observation was confirmed by FREY-WYSSLING (1930) but who also pointed out that trees with wide latex tubes were not always good yielders of rubber and that the correlation between the diameter of the latex tubes and yield of dry rubber per tree was not satisfactory. However a selection based on the criteria of both the latex vessel diameter and petiolar rubber concentration may overcome this difficulty and find useful application.

It is well known that the foliage of clone PB 86 is exceptionally prone to magnesium deficiency. It was of interest therefore to note that the laminae of this clone possessed a significantly lower chlorophyll concentration (TABLE III) and a higher K/Mg ratio (TABLE XII) than clone Tjir 1. As previously concluded (BOLLE-JONES 1954c) the higher the K/Mg ratio value the greater is the likelihood of the occurrence of magnesium deficiency symptoms; consequently the greater susceptibility of clone PB 86 to magnesium deficiency can be explained on this basis as well as being due to a lower magnesium concentration in the lamina — a difference which may not always be significant.

The difference between the laminar mineral concentrations of trees of different clones suggested if all other factors (such as number and weight of leaves per tree, distribution of nutrients within the tree, *etc.*) were equal, that their mineral uptake or requirement must have differed. It is difficult to accept the principle that clones which yield a much higher amount of latex and rubber do not require more minerals than the low yielders unless it is conceded that the selection of such high yielders has resulted in a drastic change of the tree's metabolism. Such a change would be unexpected as it is believed that the selection and breeding results merely in an increased number of latex vessels and in increased vigour and girth of tree *i.e.* an increased rate or intensification of growth, not a fundamental metabolic change which would divert the raw materials away from their

normal synthetic channels to provide for increased rubber production.

Petiolar tissue was chosen as a subject for rubber analysis rather than the lamina as it contained a much higher proportion of rubber. Nevertheless it proved possible to show that the rubber concentration of the petiole was proportional to the concentration of nitrogen present in the lamina (*Figure 27*). If it can be assumed that the rubber found in the petioles passes into the stem or trunk and ultimately into the tapped panel it is obvious that the nitrogen status of the lamina may determine, to some extent, the rubber output of the tree. Some doubt however has been cast on the continuity of the latex vessels of petiole and stem. It was claimed by BOBILIOFF (1923) that such a connection existed only when the leaves were young and that later the latex vessel system of leaf and stem was interrupted. This was later disproved by the work of VAN AGGELEN-BOT (1948) and RUINEN (1950) who established a direct connection between the latex vessels of the leaf and those of the stem. GOODING (1952) has shown that when a tree is brought into tapping for the first time, tapping resulted in a dilution of the latex throughout the tree from which it may possibly be inferred that the latex in the furthestmost branches of the tree contributes ultimately to the latex collected at the tapping panel. Consequently, although there is no direct evidence that the nitrogen concentration of the laminae may influence the amount of rubber withdrawn at the tapping panel it seems that such a relationship is highly probable. The downward transport of rubber from the petioles to the tapping panel, can only be completely proven by the use of dye injections or radioactive isotopes. If the desired proof is not forthcoming it is still fair to assume that the organic precursors from which rubber is derived are in turn derived from the products of photosynthesis and this process is dependent on a favourable nitrogen status of the laminae.

In this connection it is noteworthy that BONNER and ARREGUIN (1949) have shown that the rubber formation in young guayule seedlings can be substantially increased by the addition of leaf extracts to the nutrient solutions. It was necessary that these extracts were derived from leaves actively engaged in rubber formation and thus it was suggested, by the authors, that the leaves may have manufactured certain precursors of rubber. This conclusion is similar to the one drawn above, namely, that certain products manufactured in the laminae, and which are influenced by the nutritional status of the latter, may influence the rubber concentration of tissues external to the laminae.

It has been shown that the concentration of rubber in the petiole is dependent on the nitrogen status of the lamina which was in turn directly related to the concentration of calcium. It was interesting to note that 50% of the variation in rubber concentration could be accounted for by the variability in the nitrogen concentration. This implied that at some stage nitrogen containing compounds are essential for the synthesis of rubber

although they do not enter into the composition of the compound. BEAUFILS (1954) has shown that the yield of rubber (expressed as grams per tapping per tree) varied in the same seasonal manner as did the calcium concentration of the leaves. His results are not easy to interpret as at one stage he claimed to establish that the leaf K_2O/CaO ratio was directly correlated with either the d.r.c. of the latex or the concentration of rubber in the latex while later he claimed that the calcium concentration of the leaf was positively correlated with yield which was negatively correlated with the K_2O/CaO ratio of the leaf. Whatever the interpretation of his observations may be, the results of the present investigation indicate that the effect of calcium on rubber may well be an indirect one, caused by the correlation-ship (*Figure 32*) which existed between the calcium and nitrogen concentrations of the lamina. The fact that it is possible to obtain clear relationships between nutrient status and rubber concentration in this investigation and not consistently in a previous one (BOLLE-JONES 1954c) reflects the superiority of the use of petiolar tissue over that of bulked stems and petioles. The use of whole stems which was necessitated for young plants incurs a relative decrease in rubber concentration with time owing to the increased proportion of non-rubber tissues, whereas in mature petioles taken from same whorl position a relative constancy in the proportion of rubber bearing tissue is maintained.

The effect of rainfall on some of the variables examined was well marked. While it is frequently suggested that increased rainfall may increase the rubber obtained from a tree on tapping this investigation provides, to our knowledge, the first instance of the establishment of a direct correlation between rainfall and the concentration of rubber within the tissues. Thus it might be expected that regions of heavy rainfall may yield a higher amount of rubber per tree than regions receiving less rain. The effect of rainfall is presumably indirect and must, to some extent, be associated with soil conditions. It can be postulated that increased rainfall increased the rate of organic matter turnover in the soil and stimulated microbiological processes, such as ammonification and nitrification, which might account directly for the positive correlation which existed between laminar concentrations of nitrogen and rainfall (*Figure 25*). On the other hand, in this light sandy soil, rainfall may have enhanced directly the amounts of nitrogen containing compounds in solution which were brought into direct contact with the roots. Although the favourable effect of rainfall on petiolar rubber concentration was partially accounted for by the enhanced laminar concentration of nitrogen, the evaluation of the partial correlation coefficients governing these interrelationships showed that this effect alone did not fully account for the rainfall's beneficial influence.

Increased rainfall also increased the concentration of iron found in the laminae. If this increased concentration can be taken to imply an increased absorption or uptake of iron it can be inferred that increased rainfall enhanced the availability of iron in the soil. The effect of variable soil moisture tension on the

availability of iron and other ions may, under tropical conditions, play an important part in the successful culture of hevea. Much more information is needed on the applicability of this relationship to various soil types and it is necessary to determine whether the process is a physical one or motivated through various microbiological agents.

The concentration of rubber in the petiole and of chlorophyll, ash, calcium, iron and manganese in the lamina increased as the leaf grew older whereas laminar concentrations of nitrogen, phosphorus, and potassium decreased with age. These gradients of mineral concentration according to age of leaf fully confirm those reported previously (BOLLE-JONES 1954b). The effect of whorl position on each of the above variables was significant but whorl position had no significant effect on the concentration of magnesium and the K/Mg ratio found in the laminae. This information is of practical value when leaf analysis is used as a means of diagnosing the nutrient status of the plant; it is obvious that a comparison based on samples taken from different whorl positions may have little value and may even be misleading.

Significant effects of whorl position according to month of sampling were noted for rubber ($P < 0.05$), chlorophyll ($P < 0.001$), phosphorus ($P < 0.01$) and calcium ($P < 0.01$) concentrations. For rubber, chlorophyll and phosphorus concentrations the whorl effect was most marked in the early part of the investigation and became less marked as the plants grew older, but the effect of whorl position on calcium concentration became more pronounced as the plants grew older.

The effect of whorl position on any variable did not vary according to the clone sampled with the sole exception of rubber where a significant ($P < 0.05$) clones $\times$ whorls interaction was recorded.

The effect of date of sampling or 'months' on composition was significant. To some extent this variation may be attributed to variations in rainfall which was, as has been pointed out, capable of influencing significantly some of the variables examined. While the influence of rainfall may perceptibly influence the rubber, nitrogen and iron concentrations and thus explain part of the monthly variation it was equally obvious that where no similarity seemed to exist between the rainfall and the concentration curves that other factors must govern these seasonal fluctuations. What these factors were and how they operated are beyond the scope of this investigation. Sufficient be it to note that valid comparison between leaf analyses made on samples taken on different dates can only be made when the seasonal variation is taken into consideration.

The magnitude of the seasonal variation of chlorophyll and calcium concentrations varied with clone; these 'clones $\times$ months' interaction effects were significant at the 5% and 0.1% levels respectively. The seasonal variation was similar for both clones Tjir 1 and RRIM 501 but clone PB 86 showed a different type of fluctuation. For all other variables examined the effect of months did not vary according to clone.

SUMMARY

Leaves were removed from fixed whorl positions of young rubber plants which had been budgrafted with the following clonal scions: Tjirandji 1; Prang Besar 86; RRIM 501. These leaves were sampled, for chemical analysis, at approximately monthly intervals over the period of a year.

The concentrations of rubber in the petioles and of chlorophyll, ash, nitrogen, phosphorus, magnesium, potassium, calcium and iron in the laminae, varied according to clone. With the exception of nitrogen, potassium and iron, clone Tjir 1 contained higher concentrations of each of these constituents than the other two clones investigated. The highest K/Mg ratio and the lowest magnesium concentration were found in the laminae of clone PB 86 which is known to be susceptible to magnesium deficiency.

Whorl position markedly influenced the concentration of the foliar constituents. Thus with increased age of leaf an increase in petiolar rubber concentration and in the laminar concentrations of chlorophyll, ash, calcium, iron and manganese, occurred. Nitrogen, phosphorus, and potassium concentrations in the lamina decreased with increased age.

The effect of whorl position on the concentration of rubber in the petioles and of chlorophyll, phosphorus and calcium in the laminae varied according to the month of sampling. The effect of whorl position did not, except for rubber, vary according to the clone sampled. The importance of whorl position and seasonal variation in making valid comparisons of nutrient status was indicated.

Variation in rainfall was shown to be partially responsible for seasonal variations in the concentrations of rubber in the petioles and of nitrogen and iron in the laminae. For the other constituents other factors as well as rainfall markedly influenced the foliar concentrations.

The petiolar rubber concentration varied according to the nitrogen concentration found in the laminae; both were increased by increased rainfall. Increased calcium concentration (which was directly related to the ash and manganese concentrations) also increased the nitrogen concentration of the lamina.

It was suggested that the synthesis of rubber was at some stage dependent on the laminar concentration of nitrogen which was partially governed by the calcium present. The probability that the mineral nutrient status of the foliage may influence indirectly the amount of rubber withdrawn at the tapping panel was discussed.

We are grateful to Mr D.R. Westgarth for his advice on the statistical interpretation of some of the data and thank Mr Chin Pong Tow whose willing aid and most competent execution of the statistical analyses made possible the early publication of our results.

Soils Division
Rubber Research Institute of Malaya
Kuala Lumpur

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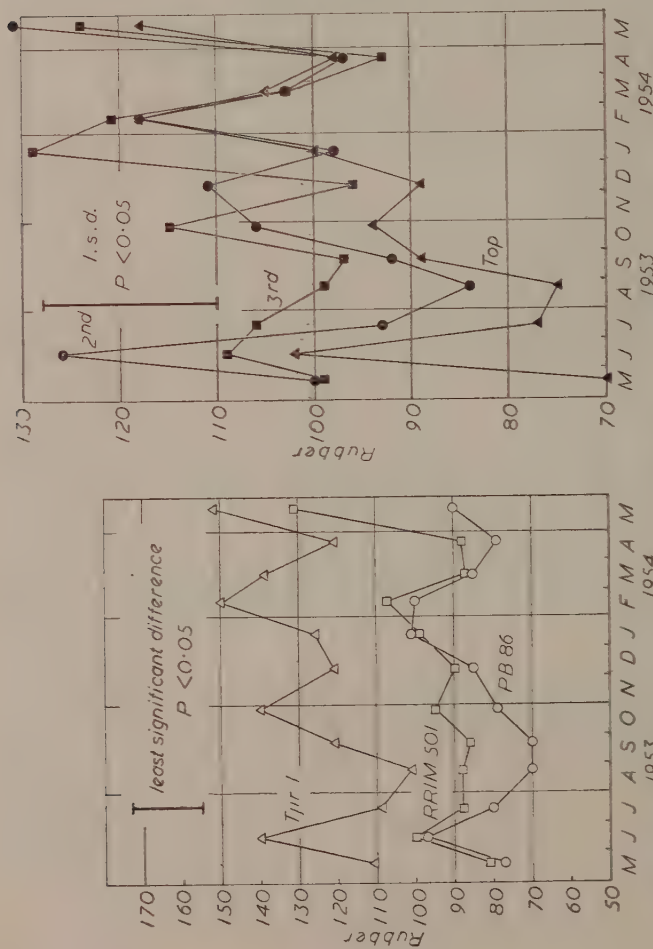


Figure 1. Variation of mean monthly rubber concentration for each clone. Concentration expressed as mg rubber/5 gm dry petiole; each point represents mean of 9 values.

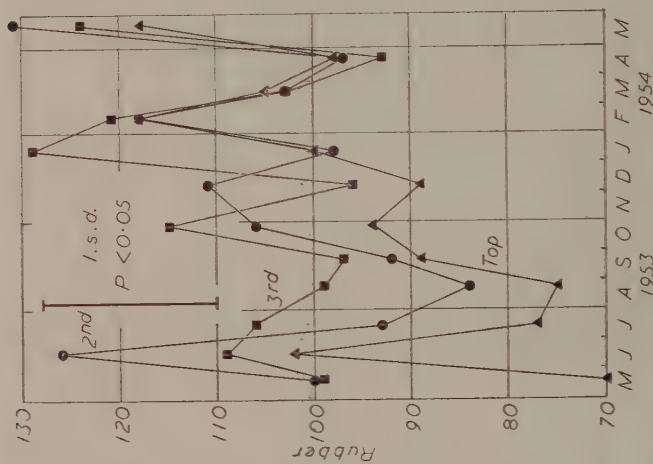


Figure 2. Variation of mean monthly rubber concentration for each whorl position. Concentration expressed as mg rubber/5 gm dry petiole; each point represents mean of 9 values.

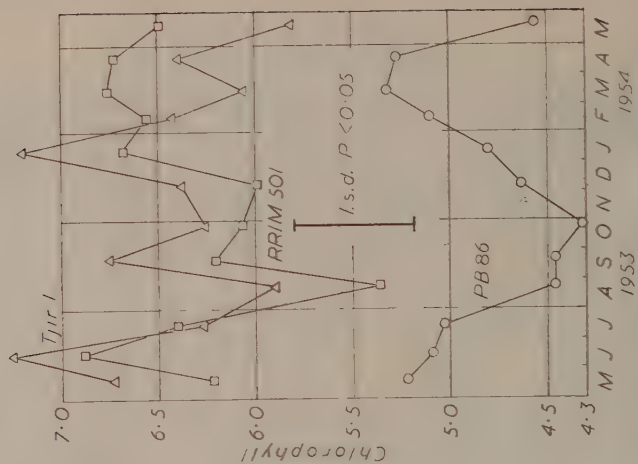


Figure 3. Variation of mean monthly chlorophyll concentration for each clone. Concentration expressed as mg chlorophyll/gm dry lamina; each point represents mean of 9 values.

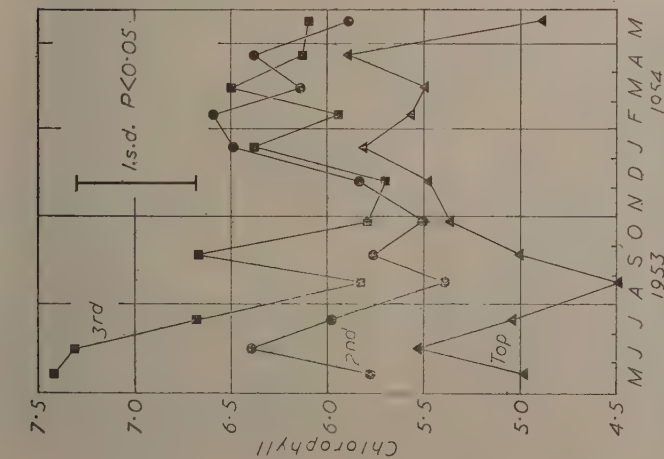


Figure 4. Variation of mean monthly chlorophyll concentration for each whorl position. Concentration expressed as mg chlorophyll/gm dry lamina; each point represents mean of 9 values.

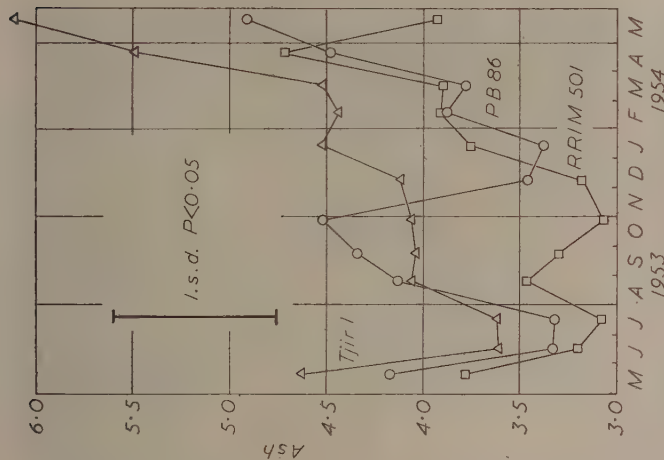


Figure 5. Variation of mean monthly ash concentration for each clone. Concentration expressed as % ash in dry lamina; each point represents mean of 9 values.

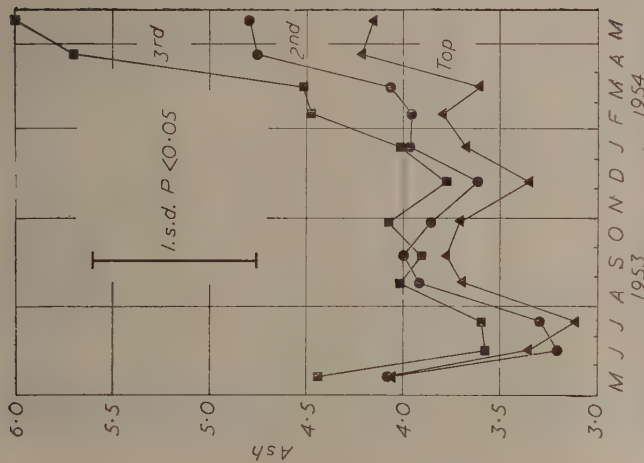


Figure 6. Variation of mean monthly ash concentration for each whorl position. Concentration expressed as % ash in dry lamina; each point represents mean of 9 values.

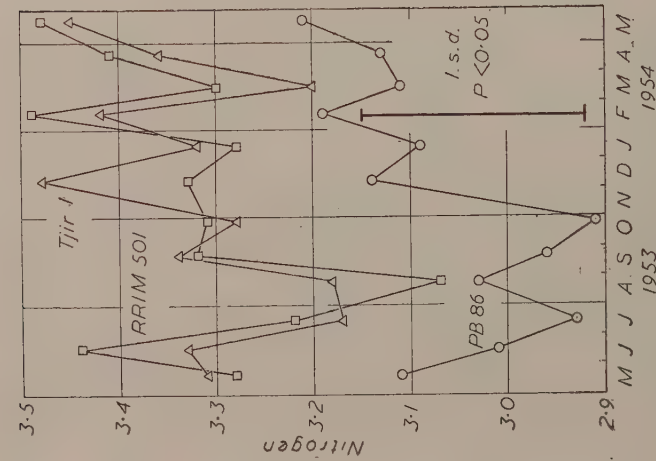


Figure 7. Variation of mean monthly nitrogen concentration for each clone. Concentration expressed as % N in dry lamina; each point represents mean of 9 values.

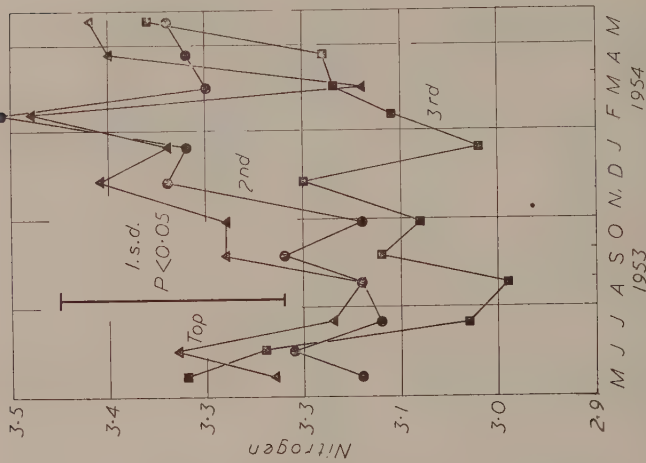


Figure 8. Variation of mean monthly nitrogen concentration for each whorl position. Concentration expressed as % N in dry lamina; each point represents mean of 9 values.

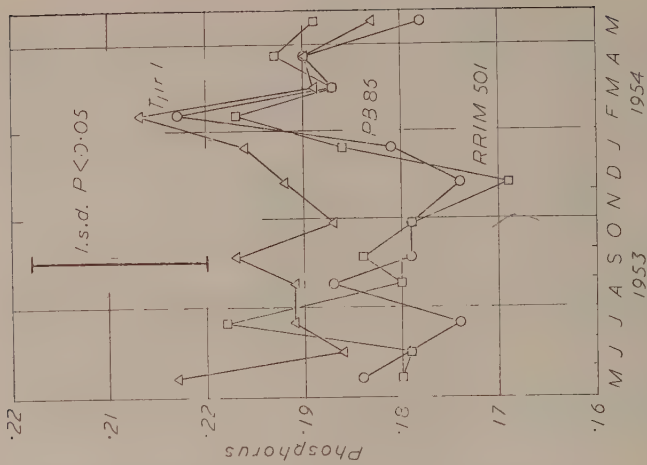


Figure 9. Variation of mean monthly phosphorus concentration for each clone. Concentration expressed as % P in dry lamina; each point represents mean of 9 values.

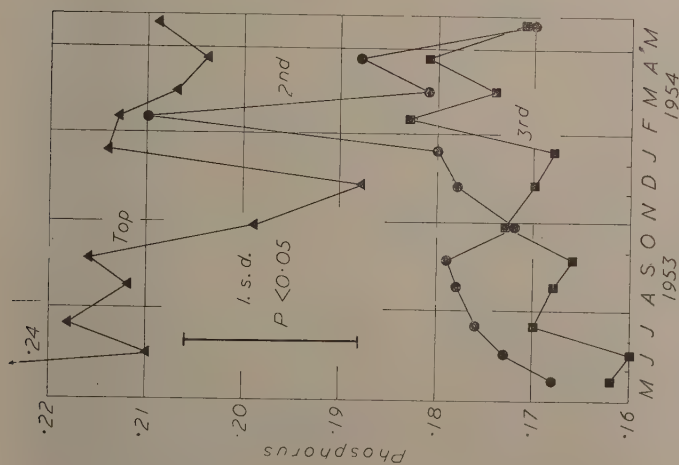


Figure 10. Variation of mean monthly phosphorus concentration for each whorl position. Concentration expressed as % P in dry lamina; each point represents mean of 9 values.

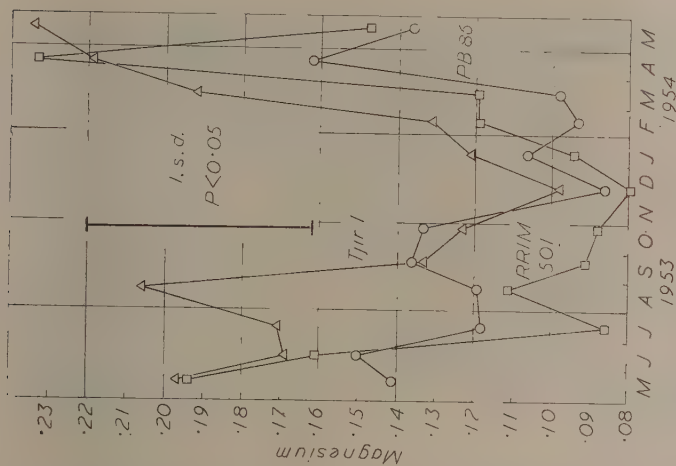


Figure 11. Variation of mean monthly magnesium concentration for each clone. Concentration expressed as % Mg in dry lamina; each point represents mean of 9 values.

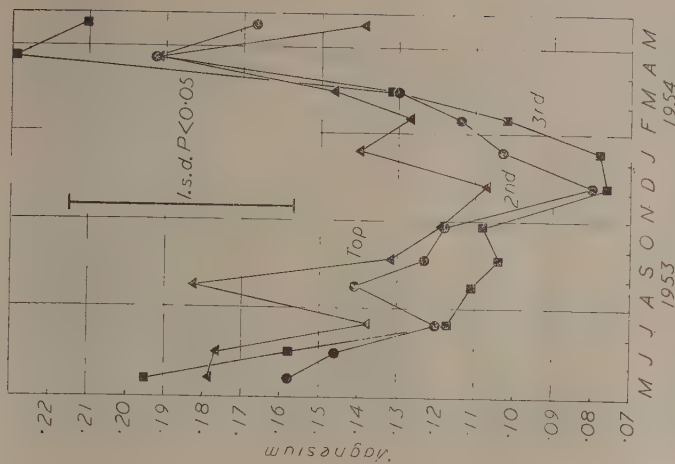


Figure 12. Variation of mean monthly magnesium concentration for each whorl position. Concentration expressed as % Mg in dry lamina; each point represents mean of 9 values.

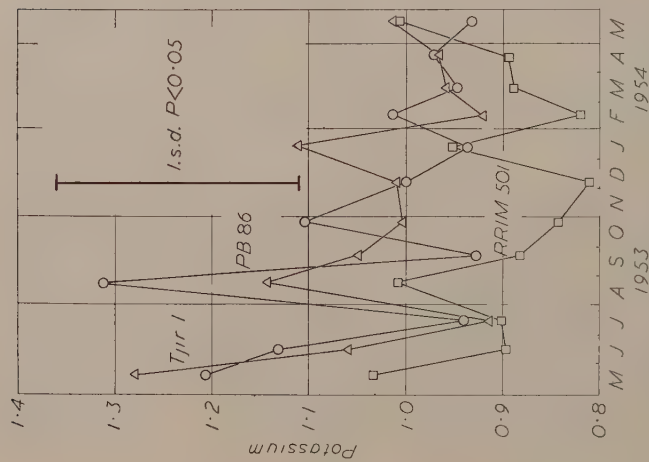


Figure 13. Variation of mean monthly potassium concentration for each clone. Concentration expressed as % K in dry lamina; each point represents mean of 9 values.

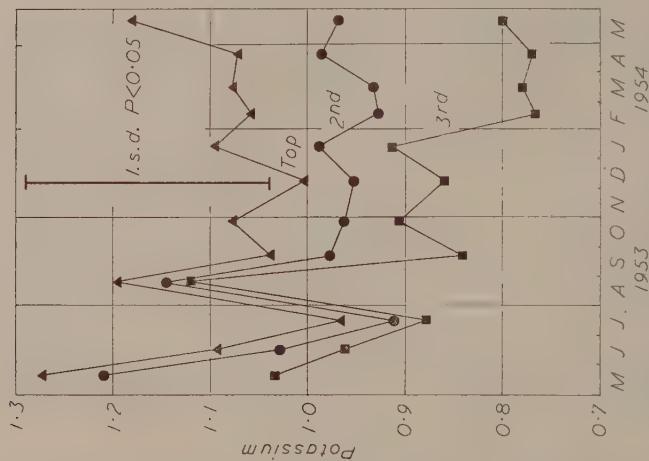


Figure 14. Variation of mean monthly potassium concentration for each whorl position. Concentration expressed as % K in dry lamina; each point represents mean of 9 values.

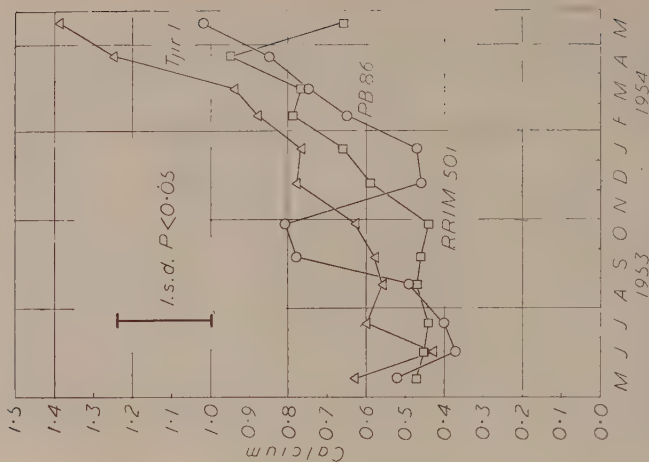


Figure 15. Variation of mean monthly calcium concentration for each clone. Concentration expressed as % Ca in dry lamina; each point represents mean of 9 values.

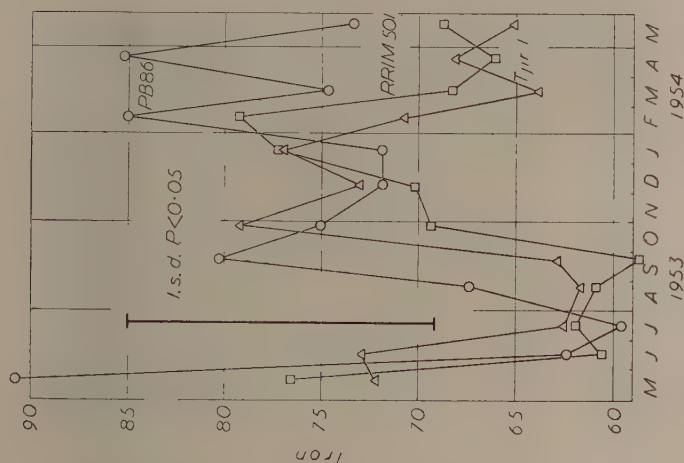


Figure 17. Variation of mean monthly iron concentration for each clone. Concentration expressed as p.p.m. Fe in dry lamina; each point represents mean of 9 values.

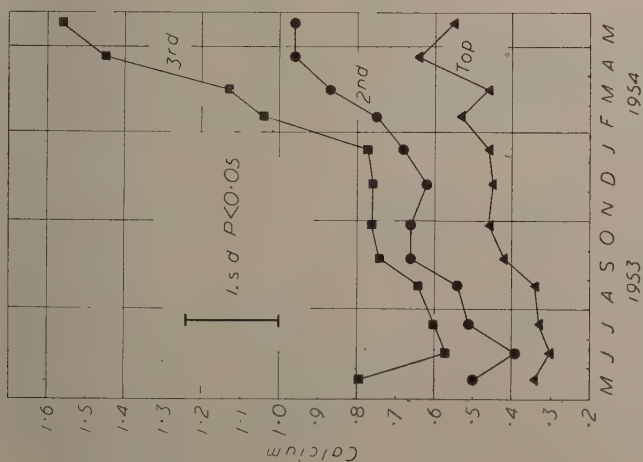


Figure 16. Variation of mean monthly calcium concentration for each whorl position. Concentration expressed as % Ca in dry lamina; each point represents mean of 9 values.

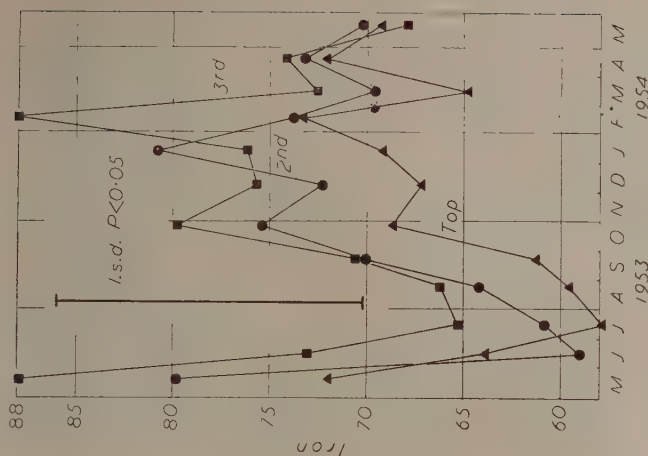


Figure 18. Variation of mean monthly iron concentration for each whorl position. Concentration expressed as p.p.m. Fe in dry lamina; each point represents mean of 9 values.

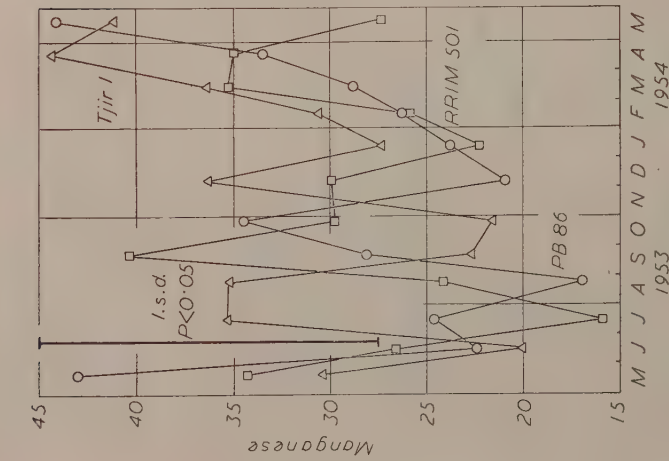


Figure 19. Variation of mean monthly manganese concentration for each clone. Concentration expressed as p.p.m. Mn in dry lamina; each point represents mean of 9 values.



Figure 20. Variation of mean monthly manganese concentration for each whorl position. Concentration expressed as p.p.m. Mn in dry lamina; each point represents mean of 9 values.

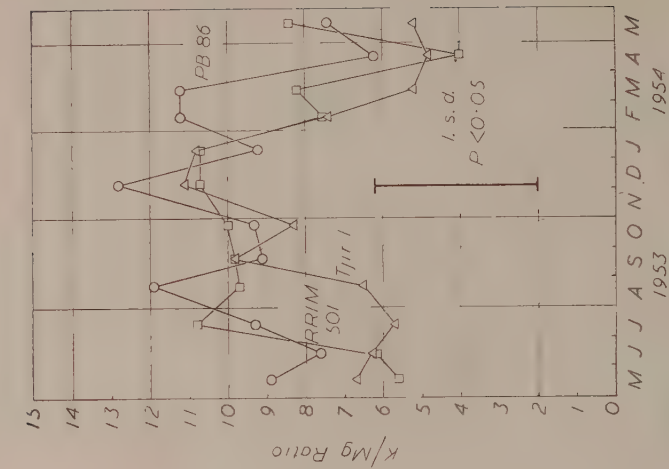


Figure 21. Variation of mean monthly K/Mg ratio in dry lamina for each clone. Each point represents mean of 9 values.

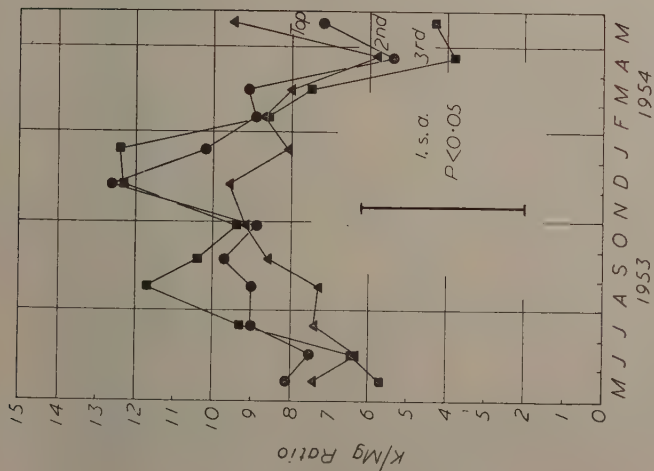


Figure 22. Variation of mean monthly K/Mg ratio found in dry lamina for each whorl position. Each point represents mean of 9 values.

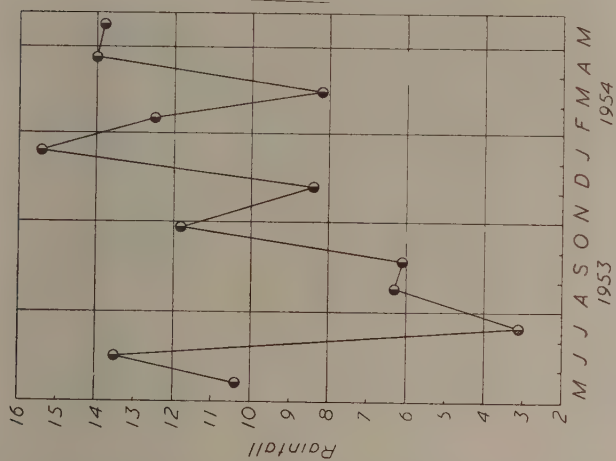


Figure 23. Inches rainfall, received in period preceding sampling date, plotted against time.

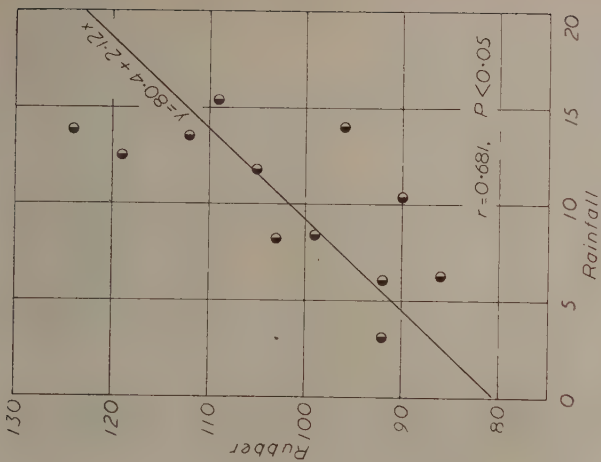


Figure 24. Variation of petiolar rubber concentration with rainfall. Rubber expressed as mg / 5 gm dry petiole and rainfall in inches. Each rubber mean value derived from 27 samples.

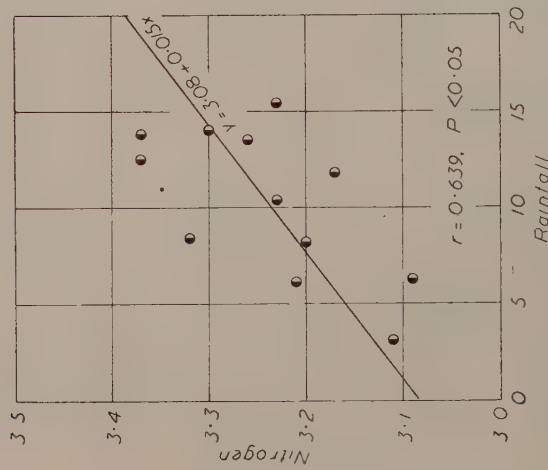


Figure 25. Variation of nitrogen concentration with rainfall. Nitrogen expressed as % N in dry lamina and rainfall in inches. Each nitrogen mean value derived from 27 samples.

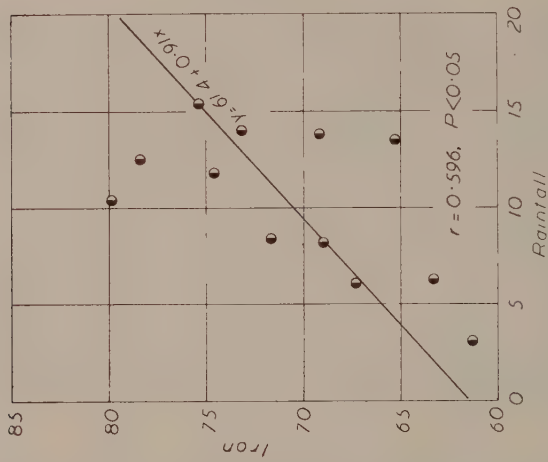


Figure 26. Variation of iron concentration with rainfall. Iron expressed as p.p.m. Fe in dry lamina and rainfall in inches. Each iron mean value derived from 27 samples.

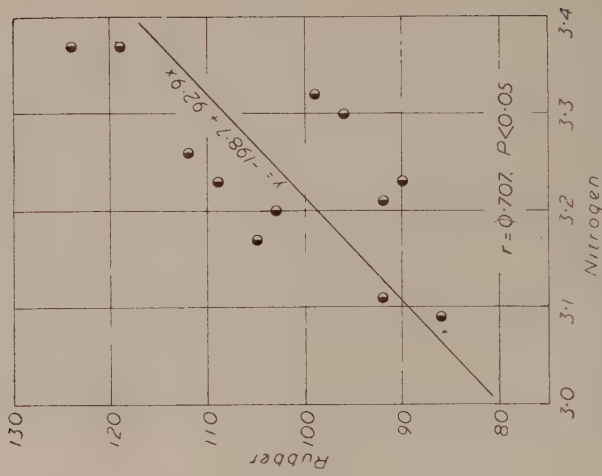


Figure 27. Variation of rubber with nitrogen concentrations. Rubber expressed as mg/5 gm dry petiole and nitrogen as a % of dry lamina. Each point based on mean values derived from 27 samples.

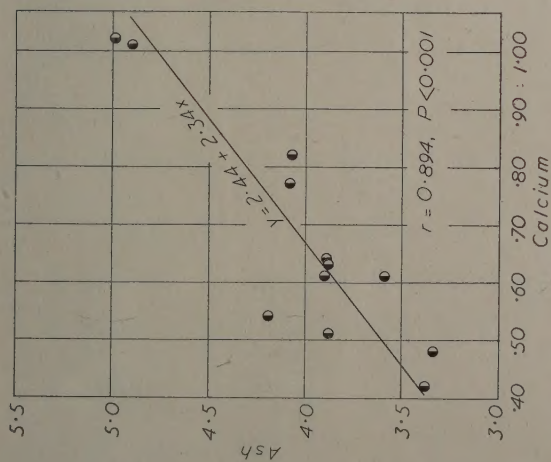


Figure 28. Variation of ash with calcium, concentrations. Ash and calcium expressed as % of dry lamina. Each point based on mean values derived from 27 samples.

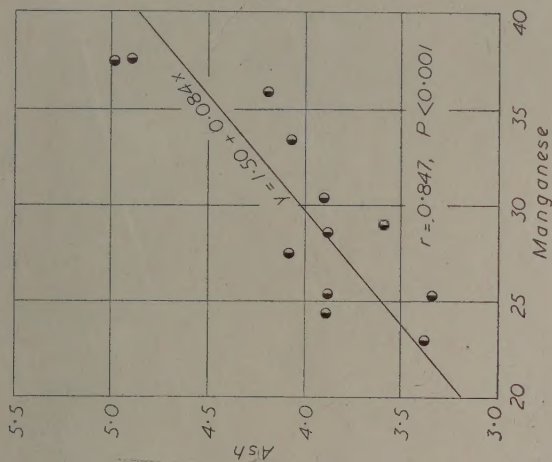


Figure 29. Variation of ash with manganese, concentrations. Ash and manganese expressed as % and p.p.m., respectively, of dry lamina. Each point based on mean values derived from 27 samples.

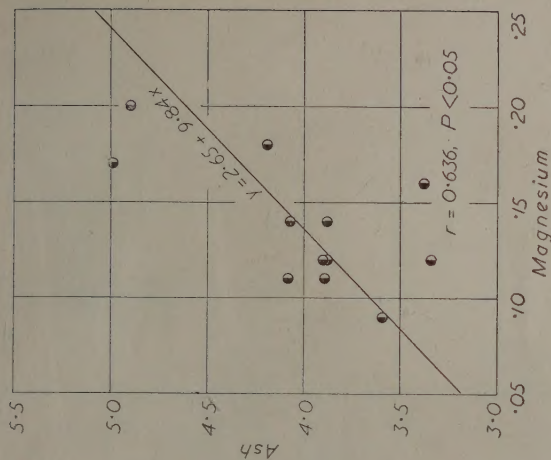


Figure 30. Variation of ash with magnesium, concentrations. Ash and magnesium expressed as % of dry lamina. Each point based on mean values derived from 27 samples.

